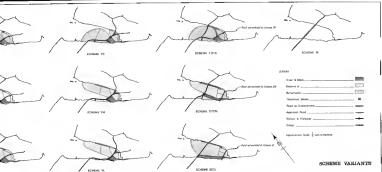
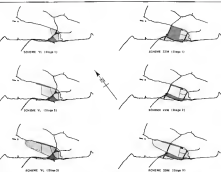


**LEGEND**

- Area of Study 
- Boundary 
- Road 
- Settlement 
- Water 
- Major road network 
- Major road network 
- Major road network 
- Major road network 
- Major road network 

**SOURCE: 2000**



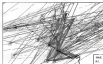


SCHEME

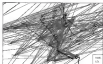
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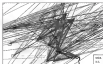
FEEDING OF TYPICAL SCHEMES



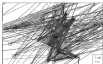
THE BRISTOL REGION



BRISTOL HARBOUR AND THE BRISTOL REGION



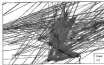
BRISTOL HARBOUR AND THE BRISTOL REGION



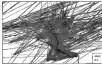
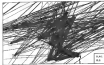
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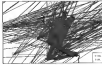
TRAFFIC DURING LUNCH (1900)

[illegible]

**Abstract**

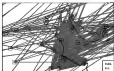
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**Abstract**

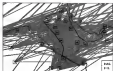


**THESE**

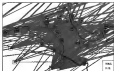
**THAT'S A LOT OF WORK FOR YOU**



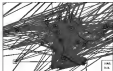
Map of the East of England



Map of the East of England showing traffic density lines



Map of the East of England



Map of the East of England showing traffic density lines

Legend			
Line	Line	Line	Line
1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32
33	34	35	36
37	38	39	40
41	42	43	44
45	46	47	48
49	50	51	52
53	54	55	56
57	58	59	60
61	62	63	64
65	66	67	68
69	70	71	72
73	74	75	76
77	78	79	80
81	82	83	84
85	86	87	88
89	90	91	92
93	94	95	96
97	98	99	100

Map of the East of England showing traffic density lines

Map of the East of England showing traffic density lines

TRAFFIC DENSITY LINES 2001



BRIDGE AT MOUTH OF RIVER



BRIDGE AT MOUTH OF RIVER



BRIDGE AT MOUTH OF RIVER



BRIDGE AT MOUTH OF RIVER



TRAFFIC FLOWS 1968



1860 - 1860



1860 - 1860



1860 - 1860



1860 - 1860



1860 - 1860

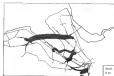


1860 - 1860

THE UNIVERSITY OF SOUTHAMPTON  
LIBRARY  
1000 UNIVERSITY ROAD, SOUTHAMPTON  
SO9 4NH



1000 FT CONTOUR



1000 FT CONTOUR LINE AND 1000 FT CONTOUR LINE



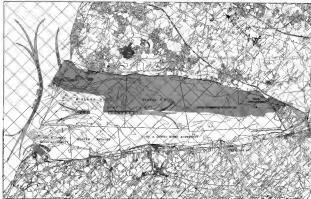
1000 FT CONTOUR LINE AND 1000 FT CONTOUR LINE



1000 FT CONTOUR LINE AND 1000 FT CONTOUR LINE



TRAFFIC FLOW 8001



# LEGEND

Marsh Flats \_\_\_\_\_

Area of Marsh Flats \_\_\_\_\_

Marsh \_\_\_\_\_

Marsh Flats \_\_\_\_\_

Marsh Flats \_\_\_\_\_

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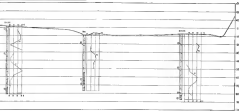
Marsh Flats \_\_\_\_\_

ESTUARY PLAN

Drawing 120







READING CURVES



1. Before using equipment in field for water logging operations, read instructions carefully.

2. Always use G.C.S.

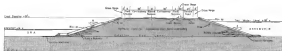
3. Always operate the equipment in the

4. Always use the correct

5. Always use the correct

WIDFELD - WATER LOGGING SYSTEM

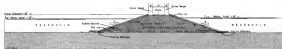
WIDFELD - WATER LOGGING SYSTEM



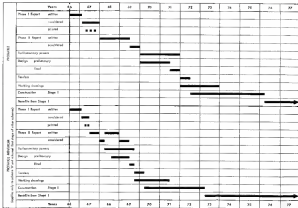
ROAD-BUILDING TYPE DAM CROSS-SECTION



GRAVELLY SAND TYPE DAM CROSS-SECTION



TYPICAL  
DAM CROSS-SECTIONS



## DEE CROSSING STUDY - PHASE I

### PART 1 - SUMMARY REPORT

#### 1.1 INTRODUCTION

##### 1.1.1 Historical

(a) For over two centuries man has sought to train the river Dee and to control its estuary, to use the factor of accretion for gaining land and yet to stem the steady decline of navigation. In the 1730s, Kindersley started training the river from the Cheshire side of the estuary on to the Flintshire side, a process which continued with the 19th century re-claimations until final closure of the "Broken Bank" in 1916. Thus embankment works are no new concept in the estuary and a look at Sealand on the map shows how large an area has already been enclosed. Although, around 1930, estuary crossings were mooted from Point of Air (then from Greenfield) to West Kirby, between the two world wars emphasis was still upon trying to save the navigation interests by river training to stabilize the estuary channels. Model tests were done on this for the Dee Conservancy Board from 1937 to 1939 by the late Professor A. H. Gibson of Manchester University and Dr. Jack Allen (now Professor at Aberdeen University).

(b) In the mid-1950s, Flintshire County Council were actively pursuing the idea of an estuary crossing and Professor J. A. L. Matheson of Manchester University was commissioned by the Dee and Clwyd River Board to review the previous work, carry out model tests and report. The outcome of this restricted study was that an embankment and bridge on a Greenfield-Gayton line were favoured, with river training, a small tidal basin and some 11,600 acres of reclamation; recommendations were made for further study. In 1962, the Hydraulics Research Station confirmed this view but also recommended investigating enclosure of the whole estuary. The Flintshire County Surveyor, Mr. E. W. W. Richards, documented the Matheson work in July 1965, adding a commentary and note of further information needed.

(c) By the mid-1960s, Cheshire County Council and other authorities were also actively focussing attention on implications of estuary development.

(d) A Dee Crossing Steering Committee and Technical Working Party (see appendix A1) were therefore formed in 1965. Phase I of the present study was started on 2nd June, 1966 under an agreement with the Ministry of Land and Natural Resources, with whom the two County Councils and the River Authority are associated in financing the work.



### 1.1.2 Terms of reference

The terms of reference are listed in appendix A2.

### 1.1.3 Interpretations

(a) At meetings of the Working Party on 28th July and of the Liaison Group on 5th October, 1966, the study team's interpretation of the primary aims of the Phase I study, to be read in conjunction with the terms of references, was given as follows :-

- (i) maximum elimination of alternatives amongst the following:-
  - barrage lines and approach roads
  - barrages and bridge
  - reservoirs and retention levels
  - land reclamation
  - coal mining
  - ports and navigation;
- (ii) guidance on model tests at Hydraulics Research Station;
- (iii) clear outline plans of probable scheme(s);
- (iv) preliminary estimates of capital costs, running costs and indirect costs, the benefit-cost relationship expressed in some form;
- (v) recommended programme for the next phase.

(b) During the investigations, an interpretation of possible scheme objectives has also been compiled and this is reproduced in appendix A3 as an aid in comparing schemes.

## 1.2 OUTLINE OF STUDY

### 1.2.1 Hydraulic model

In 1965, the Dee and Clwyd River Authority commissioned the Hydraulics Research Station, Wallingford, to build a model of the Dee estuary and to test the effects of crossings and related work in the estuary. The model was built and is nearly proved (see report in appendix B1) ready for the first tests under guidance from the consulting engineers.

### 1.2.2 Scope of study

The study has comprised :-

- (i) meetings, consultations and/or correspondence with : the Technical Working Party and its Liaison Group; individual members thereof and of the Steering Committee; many other authorities, bodies, universities, contractors and individuals (appendix B2);
- (ii) preparing geological appendix B3;
- (iii) preparing, letting, supervising and administering a competitive contract for limited site investigations, including land and marine borings, soil tests and seismic trials (appendix B4);
- (iv) visits to: the counties of Flintshire and Cheshire; the river, its estuary perimeter and the various sites; National Trust sites and areas of special scientific interest; coastal and inland areas of amenity and otherwise; Delta scheme, Delft and De Voorst hydraulic laboratories, Delft soil mechanics laboratory, Holland; reclamations at Tilbury Docks and Grays Thurrock; La Rance project; Southport, Ainsdale, Liverpool, Wallasey, Prestatyn, Rhyl, Port Meirion;
- (v) data collection from: (i) and (iv) above; the literature (appendix B5); industrial survey in Flintshire;
- (vi) economic and/or engineering researches and studies on all special aspects: population, employment, industry, road improvement programmes, railways, hydrology (including flooding, drainage, effluents, estuary siltation), fisheries;
- (vii) preliminary resolution of economic conceptual problems: highways, traffic, tolls, tourism, land, water, fisheries;
- (viii) preliminary design of many schemes, more detailed design of embankments, closures, scour protection; cost estimates and evaluation of benefits;
- (ix) initial investigation into land ownership in the estuary;
- (x) reference to other relevant studies as needed: e.g. regional studies, various traffic studies outlined in section 2.2.2;
- (xi) assessment of need for mathematical model to determine effects on coastal regimes.

### 1.2.3 Assumptions and limitations

The main assumptions and limitations in the study are described in the text but, to enable them to be taken readily into account, they are also listed and/or cross-referenced in appendix B6.

## 1.3 OUTLINE OF REPORT

### 1.3.1 Arrangement and content

The summary report comprising part 1 contains material not repeated elsewhere. In parts 2 to 5 are described the potentials of each aspect of estuary development, appraisals leading to the final range of developments and outlines of the economic background and of special engineering factors related to works in the estuary. Further detail is given in extensive appendices, which are followed by the drawings. In general, the text has been much condensed to show only typical data and the more important assumptions, calculations and results; the aims have been to show what has been done, so that the specialist reader can judge whether he wishes to pursue any aspect in technical discussion during consideration of the report.

### 1.3.2 Communications

The first and most detailed study in part 2 deals with estuary crossings in relation to the present and future highway networks. The traffic study and the various crossing and approach road proposals are described. The need for an estuary crossing scheme is fully demonstrated. Proposals for a rail crossing, on the other hand, seem fraught with doubt but some possibilities for rapid transit road/rail interchanges in the Wirral are outlined. Pending hydraulic model tests, the rate of further deterioration in the navigable channels cannot be predicted. The problem is discussed in the context of the viability of investment in port and navigation facilities and in the light of documented experience in this and other estuaries. The use of Dee estuary land for an airport is considered unlikely, at least in the coming two decades.

### 1.3.3 Water

Reservoirs behind barrages and fed by gravity are studied but firmly rejected in favour of pumped-storage hunded reservoirs within the estuary, for reasons which include the safety and reliability of supplies, the economics of staged construction, the cheapness of dredged sand bunds, water quality, amenities, the salmon fisheries and varied recreational facilities. Hydrology and water quality are dealt with in detail but, in the latter context, it is pointed out that the Dee is still clean enough to be a flourishing salmon river and that

### 1.3.3 Water (cont'd)

several water undertakings already abstract water from near the present tidal limit. Difficulties in valuing water supplies are described and a tentative valuation is given for Phase I purposes. Questions of flooding, drainage and effluent treatment are discussed where appropriate in various sections of the report.

### 1.3.4 Amenities, nature conservation and recreation

The schemes are then considered from the viewpoints of amenity, nature conservation and recreational use; in general, economic assessment of these is not attempted but the implications are described. A memorandum kindly contributed by the Nature Conservancy is reproduced in appendix F1.

### 1.3.5 Other land uses

The possible extent, types, methods and costs of land reclamation in the estuary, together with various uses and limitations, are outlined. Although the potential attraction for development is also discussed, no estimate could be made of a demand for land reclamation in the estuary; use for housing and industry are considered to be subject to planning control rather than to market forces. Agricultural use is limited due to the cost of treatment of all but the well established marshes. The National Coal Board no longer expect to find a major opencast reserve in the estuary although a small area off Neston may yet prove to be economic. For present purposes, schemes have been illustrated with arbitrary areas of land reclamation.

### 1.3.6 Fish

Specially detailed attention has been given to and is proposed for solving the migratory fish problem; the various proposals result from advice taken from several experts on the subject. Implications to sea fisheries and of trout and coarse fisheries are described.

### 1.3.7 Range of schemes \*

(a) The illustrations in this report might have been limited to showing, say, two viable pure crossing schemes and three multi-purpose schemes (outer, mid-estuary and inner zone), giving costs of each based on similar assumptions. Consideration of these schemes would have sufficed to justify: (i) discarding all outer zone schemes, (ii) regarding single, inner zone crossing schemes as viable by-passes to the Queensferry/Connah's Quay area and (iii) deducing that the best

\* Before reading further, it may be helpful to note the main conclusion and recommendation of the report in 1.4(a) on p. 11.

location for a multi-purpose scheme would be in the upper half of the estuary. Indeed, until recently, it was thought that even this much elimination of alternatives would be a most satisfactory outcome of Phase I. In the event, however, it has been found feasible and considered useful, not only to provide enough data to enable this to be done, but to take the "generalized" mid-estuary multi-purpose scheme a stage further by illustrating typical variants. For these, however, only ranges and trends of costs and benefits are quoted, because it would be both misleading and outside the accuracy of Phase I to quote detailed numerical comparisons. The objects of showing the variants are to aid the decision upon whether to proceed with a pure crossing or a multi-purpose scheme and, if the latter, to attract constructive comment in the early stages of considering the report; this comment would be based on only qualitative comparison but could clearly give the Phase II detailed study and the process of reduction to a few specific schemes a most useful start. Early results coming from the hydraulic model tests, further site investigations, preliminary design and other studies would then enable valid financial comparisons to be made and hence one specific scheme to be advanced.

(b) The schemes and variants illustrated (drawing 5, with larger-scale examples on drawings 2 to 4) are :-

multi-purpose schemes	W - single bridge crossing from Greenfield to Gayton.
	X - single estuary crossing by embankment and bridge, with sluices at the head of the estuary.
	XX - as X but also with inner zone road across the sluices.
	Y - two pairs of approaches, combining into one road which crosses the sluices.
	Z - single estuary crossing as X but over a closure incorporating sluices.
	ZZ - as Z but also with inner zone road across a short bridge.

Each of three estuary alignments is denoted by a suffix to the designations: 'L' for left bank (viewed down the river), 'M' for middle and 'R' for right bank. A refinement described for the scheme Y road alignments (not illustrated, denoted as YV for future reference and for study in Phase II if the general type Y schemes are favoured) would entail separated roads crossing at an interchange in the estuary and with modified approaches. (Types of crossing scheme also considered comprise use of the highway alignments of all the above schemes, with the crossings built mostly on embankments, implying acceptance of accretion, deferment of water conservation and possibly the cost of providing a mere, either close to the Wirral shore or obtained by canalizing the river).

1.3.7 Range of schemes (cont'd)

(c) Staged construction of typical schemes is illustrated on drawing 6.

(d) The schemes are deliberately drawn in stylized form at this stage to show that they are still scheme types i.e. to avoid the appearance of having been designed in detail or "landscaped". They are described in more detail in part 3.

(e) That the choice of schemes has been narrowed down to variants of mid-estuary schemes, some not unlike those in the Matheson studies is interesting but fortuitous, because those studies were limited to the hydraulic behaviour of the estuary and had rather different aims; the present schemes have evolved from other and wider considerations.

(f) Again, any resemblance to barrage water schemes is fortuitous and is due to the primary need for a road crossing and the incidental factors that the enclosing banks of pumped storage reservoirs can carry good roads at small extra cost and are themselves cheaper if protected from the sea action by road or other embankments.

(g) Such an array of main variants - which is still not exhaustive due, for example, to the unknown proportions of any land reclamations required - may seem formidable but much of the elimination process in the first part of the Phase II work would be straightforward :-

- (i) the early hydraulic model tests would show whether a long and narrow (types X and Y) or a short (type Z) estuary is needed for maintaining the most favourable channels and estuary shapes. This could reduce the variants to six or nine;
- (ii) the Phase II traffic study would distinguish more accurately between the merits of the double crossing (XX, Y and ZZ) schemes in relation to the single crossing (X and Z) schemes. This would reduce the variants to three or six;
- (iii) although site investigations of Bagillt Bank might reveal difficulties of estuary alignment (L) close to the Flintshire shore, the model tests would give general guidance on which of the alignments (L, M or R) is most favourable hydraulically and would reveal the respective implications of accretion downstream. This could help in the final reduction to one multi-purpose scheme with a definite road pattern and particular estuary length and

### 1.3.7 Range of schemes (cont'd)

position. Concurrently however with the above processes, some of the dominant matters of policy as regards water supplies, amenities, other land uses and navigation would be crystallizing as the detailed economic implications also became available, enabling a final scheme and its stages of construction to be delineated. Indeed, certain of the policy decisions in principle (chapter 1.5) which could be made early would themselves help greatly in the elimination process and, in turn, reduce the number of model tests required.

(b) Although, from considerations of engineering viability and a consensus of known requirements, a recommendation might have been made now to adopt just one apparently attractive and viable type of staged multi-purpose scheme, such a procedure would be incorrect before those taking decisions have had the opportunity to study all the implications and before their resulting comments have been taken fully into account. Thus it is suggested that the proper course of action is to proceed, step-by-step, with the decisions and elimination processes outlined, in the interests of ensuring that the scheme finally advanced is - and is known to be - the best possible.

### 1.3.8 Economic considerations

The main text continues in part 4 with an outline of the more technical economic considerations. Main principles are described and illustrated by examples from the individual valuations in the appendices. The discount rate applied to the calculations throughout is 8%. Notes are included on the uses of benefit-cost calculations and on how the relationship can be expressed. Problems of multi-purpose allocation of costs, consistency of evaluations and distributional aspects are described.

### 1.3.9 Engineering

The more technical engineering considerations in part 5 mainly comprise a selection of aspects of special application to the works in the estuary.

### 1.3.10 Timing, staging and progress

(a) Allowing for obtaining parliamentary powers and with normal procedures, benefits from even a modest first stage of a Dee estuary scheme could hardly start accruing before 1973, with a more probable

### 1.3.10 Timing, staging and progress (cont'd)

date of 1976 (drawing 18). This is because, even with a multi-staged scheme, the implications of the whole scheme would still have to be considered beforehand. Statutory procedures and finance govern the timing as much as does the engineering. (Only in emergency, with compulsory powers, could an estuary crossing, land reclamation and water supplies be implemented in months rather than years, by taking more risks, by using some temporary structures and perhaps at more cost in the long term).

(b) Even allowing the full two years for obtaining parliamentary powers, it is reasonable to quote the mid-1970s for benefits to start accruing from this project because progress has already been greatly helped for many reasons :-

- (i) Phase I has been intermediate between a desk study and a full feasibility study. This limitation resulted from the Government's policy, from mid-1965, of deferring expenditure on capital projects. Despite this and although the project had been conceived originally as a road crossing, in effect this has been the first big multi-purpose study of this kind. The terms of reference required most relevant interests to be considered and the Technical Working Party, representing these interests, collectively and individually provided help and guidance; nor have any restrictions been placed upon consultations with other bodies. Thus a team of economists as well as communications and water engineers could be deployed on this work;
- (ii) the site investigations were limited but sited mainly in the mid-estuary region and, in the event, this has proved to be the zone of most interest;
- (iii) reclamations and training works had been accomplished previously in the estuary and results of the Matheson study were available;
- (iv) an aerial survey and other investigations had already been carried out for the hydraulic model;
- (v) due to the foresight of the River Authority and the counties of Flintshire and Cheshire, the hydraulic model has already been built and largely proved; despite some delays, it has reached the right stage of development exactly when needed i.e. at the time of submission of this report; it would have been of little use for an outer line scheme, would not be needed for a bridge crossing but would be essential for any mid-estuary multi-purpose scheme;

1.3.10 Timing, staging and progress (cont'd)

- (vi) traffic studies could be based upon wide information and experience on traffic problems and patterns in the area, including traffic counts previously carried out;
- (vii) more progress than thought possible, even until quite late in the study, has been made in the elimination of the many alternative possibilities for the estuary;
- (viii) data on winds, waves, tides and surges have been collected and studies made on the hydrographic and constructional aspects of tidal closure and embankments; in the light also of recent closure experience in Hong Kong and study of Dutch closures completed or planned, the feasibility of closures in the Dee estuary has been established and the orders of costs of closure and of embankment construction have been assessed. Only if the recommended schemes had been on an outer line would statements about feasibility and total cost implications have had to be qualified;
- (ix) the hydrology of the upper Dee is quite well established and that of the whole river could be predicted with some confidence; several water authorities abstract river water from near Chester and treatment methods are known; the Water Resources Board (see 3rd Annual Report pp 23, 24) have chosen the Dee for various research studies; virtually no salinity problem would arise with pumped storage reservoirs since seepage would be outwards; reservoir biology problems (e.g. algal growths) have been overcome for river waters of lower quality than the Dee. Thus all water conservation aspects can be predicted with reasonable confidence;
- (x) if solution of the water conservation problem had lain with a barrage retaining a large low-level lake, more doubts would have had to be raised about biology, salinity, pollution, water quality and treatment costs (i.e. the safety, reliability and costs of supplies) and about migratory fish;

(c) The only major doubts concern (1) navigation (2) whether stabilizing work is needed for the estuary sands and (3) the extent to which the costs can be reduced and the estimates of benefits refined. Feasibility is stated with confidence and the first 9 months of hydraulic model tests in Phase II would be largely devoted to studies and interim reports on maintaining the estuary for navigation. More site investigations, studies and some large-scale tests (appendix B7) are still needed but mainly in order to delineate one specific scheme and to refine costs and benefits so that parliamentary procedures can be set in motion if desired.

#### 1.4 CONCLUSIONS AND RECOMMENDATIONS

(a) The main conclusion from the study is that a middle to inner zone, staged multi-purpose scheme, of one of the variant types X to Z illustrated, would be the most satisfactory and viable development of the Dee estuary. It is recommended that Phase II should proceed accordingly.

(b) The more detailed conclusions and recommendations from the Phase I study are that :-

- (i) the engineering of pure crossing or multi-purpose (crossing, water, amenity, reclamation) schemes anywhere within the estuary would be feasible;
- (ii) nevertheless, all outer zone schemes should be rejected now for the economic, social and other reasons listed in part 3 (see also (vi)B below). In this context, outer zone refers to a broad band between Point of Air/West Kirby and Mostyn/Caldy lines;
- (iii) there is a clear case for middle/inner zone crossing(s) of the estuary;
- (iv) crossings (other than near the head of the estuary) built mostly on embankments, even with several bridge spans, would change the estuary regime and accelerated silting could be expected both upstream and downstream; although this type of crossing would be much cheaper than a continuous series of bridge spans, it should be incorporated in a planned multi-purpose scheme;
- (v) the best form of water conservation scheme would be pumped-storage reservoirs rather than a true barrage scheme retaining a gravity-fed lake; enough pumped storage reservoirs ultimately to supply some 300 mgd \* (a reasonable future use of Dee resources) could be sited mainly in the upstream half of the estuary and still give large acreages for other purposes; there would be no serious seepage, salinity or water treatment problems;
- (vi) the more significant, measured benefits and costs are as shown in the following table but attention is drawn to the appraisal in part 3, economic considerations in part 4 and further details in appendix E9:-

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\* million gallons per day.

Type	Description	Benefits & costs discounted to 1976 @ 8% (1966 prices)	
		measured benefits £ million	measured costs £ million
Bridge crossings only	(1) Outer zone bridge (narrower bridge than for scheme W due to less traffic)	30	35
	(2) Inner zone crossing (by-pass to Queensferry/Connah's Quay area, including extensive improvements to approaches of crossing)	12	9
	(3) Scheme W - middle zone bridge (Greenfield - Gayton)	45	40
Separated purposes (not proposed as schemes)	(4) Middle/inner zone crossing(s) on embankments and bridges, with some river training (no water supplies)	45	25
	(5) Water supplies	70 (40)	55 (30)
Multi-purpose	(6) Scheme types X to Z	115 (85)	75 (50)
	(7) Outer zone barrage, with middle/inner zone crossings	120 (90)	105 (85)

NOTE: Benefits and costs for water supplies are for an annual rate of demand increase of 10 mgd, amounts in brackets being for 5 mgd; costs include £35m (or £17m for 5 mgd/year increase) for treatment and transmission.

The table should be read with the following considerations in mind :-

- A. the benefit-cost relationship alone should not guide the investment decision for reasons discussed in part 4 - the most important being the greatly varying size of investment involved and the intangible and other factors not measured in Phase I;
- B. The outer zone bridge costs, (1) in the table, exceed the benefits. Outer zone multi-purpose schemes (7) clearly cost far more than middle/inner zone schemes (6) for comparable benefits and, for reasons given in part 3, outer zone schemes would impose other serious (but unmeasured) costs;
- C. the inner zone single crossing (2) involves much smaller investment and confers much smaller benefits than other schemes (see also F below);
- D. scheme W(3), is barely viable as a bridge but is shown because the same benefits for much less cost could be obtained as a part, (4), of a multi-purpose scheme (6) - the crossing(s) being built on embankments and short length(s) of bridge;
- E. there would be no question of (5) being developed as a scheme on its own for water supplies, amenity, recreation and minimal land reclamation, since the main object is to provide a road crossing. On the other hand, if water supplies were not to be provided, (4) might be made acceptable only by conversion to layouts similar to (6) but with water conservation replaced by salt or fresh water meres and more land reclamation; in that case the measured benefits and costs would each be rather more than those of (4) but the increases can be ignored for purposes of discussion in F below;
- F. it would be misleading to take, as an indication of demands likely to be made for public investment, a comparison of the costs of (2) or (4) with those of (6); the great difference is the 300 mgd of water which, if not supplied from the Dee estuary, would have to come from elsewhere at a cost (including the extra transmission) taken as £70m, i.e. the measure of benefit used for Dee estuary supplies. Thus, if the magnitudes of public investment are to be compared satisfactorily, the £70m may be added to (2) and (4), giving :-

	Description	benefits £m	costs £m
(2+)	inner zone crossing (plus alternative water supplies)	82 (52)	79 (49)
(4+)	middle/inner zone crossing(s) (plus alternative water supplies)	115 (85)	95 (65)
(6)	scheme types X to Z (with Dee estuary supplies)	115 (85)	75 (50)

as before, the amounts in brackets apply to the slower rate of demand increase of 5 mgd/year. The cost saving of £20m (or £15m) on total investment in favour of (6) compared with (4+) includes £5m for the multi-purpose savings; these last would still accrue even if alternative sources of 300 mgd could be so staged and were so cheap that they could supply the Dee's area at the same cost as from Dee estuary supplies (i.e. Dee water benefits no greater than costs). Higher benefits would accrue for the more favourable facilities of (6) compared with those of (2+);

- G. the costs of £75m in (6), at least £35m of which would have to be invested anyway in treatment and transmission of water supplies from some source, imply an upper limit cost of £40m for the crossing(s), water conservation and other purposes regarded as the estuary works. Again, the total of £75m represents an upper limit, not only because it is based upon the higher increase rate of 10 mgd/year, but because some of the highway and all the water developments in schemes X to Z would be staged and the investment could be reduced or halted at any time if predicted requirements proved to be too high;

- (vii) hence scheme types X to Z, (6) in the tables, are considered the most economic types of over-all investment;
- (viii) the unit costs of water are as given on the last page of appendix E5;
- (ix) substantial evidence has accrued that a middle/inner zone multi-purpose (crossing, water, recreation, amenity, reclamation) scheme is favoured and the above confirms that such a scheme would be viable; the choice, of course, will rest upon over-all considerations of social and economic policy but the concept does widen the scope for the economies and flexibility of staged construction and leads to interesting and attractive variants of a middle zone crossing scheme e.g. a further crossing near the Broken Bank (schemes XX and ZZ) or a crossing with two pairs of approaches (scheme Y);
- (x) the provision of quick communications with the Port of Liverpool, Speke Airport and existing service industries, adequate water supplies, land reclamations if required near the industrialized upper estuary zone, amenity views for housing and recreational facilities, should all create conditions attracting industry towards North Wales and should stimulate the economy of the area;

- (xi) apart from pure crossing schemes, all schemes would reduce the estuary tidal cubature (volume swept by the tide); hence navigation channel depths are expected to decrease more quickly but, pending hydraulic model tests, no-one can predict the extent of this, the effects upon the small port of Mostyn or whether any mitigating steps could be taken - this last is doubtful but well worth testing; in the meantime, the "estuary shapes" embodied in the schemes may indicate a way of gaining some control of the future estuary regime (as well as being most favourable for migratory fish); some tests on the use of tidal flushing basins would be worth-while. Maintaining, let alone improving the ever-diminishing navigation facilities to the upper estuary seems uneconomic and incompatible with other estuary uses but, again, some tests could be carried out on the model;
- (xii) with the multi-purpose schemes, the danger of flooding downstream of Chester weir would be reduced and the incidence of flooding upstream could be slightly improved by suitable weir bypass arrangements; land drainage downstream of the weir would be marginally improved;
- (xiii) there are better forms of agricultural investment than conversion of Dee estuary sands and muds to agricultural use behind a barrage; no evidence has been offered or discerned nor any wish evinced for covering most of the estuary with industrial development and/or housing - rather the reverse - the most economic and acceptable covering for the estuary being water with some marginal reclamations, which also best meets the needs of water conservation, amenity and recreation; nevertheless, flexibility exists in the proposed schemes for varying the amounts of land reclaimed;
- (xiv) amenity and recreational facilities which could be provided by multi-purpose schemes could make a significant contribution to the region;
- (xv) on balance, the schemes proposed could benefit the interests of nature conservation by retention of an estuary and the addition of a variety of lakes, meres and nature reserves;
- (xvi) in order that salmon fisheries would not suffer, positive and extensive steps are recommended to anticipate any adverse effects of estuary works and, in the long term, to induce at least marginal improvements;

- (xvii) sea fisheries would not suffer with middle/inner zone schemes and provided that trade wastes being diverted past the estuary works were diffused into the body of tidal flows and were not concentrated into the sea fish nursery zones;
- (xviii) the likelihood of a cross-Dee estuary rail link is so remote that it should not influence scheme layouts unless, after submission of this report, the British Railways Board become interested in a middle zone crossing. A road/rail interchange e.g. near the Wirral approach to an estuary road crossing should be considered in the context of current transportation and land use studies;
- (xix) interest in coal mining in the estuary has waned but the proposed schemes could be adapted so that opencast mining could proceed, if viable, in the upper estuary area;
- (xx) thus road crossings, water conservation, preservation and diversity of amenities, scientific interest and fisheries, provision of a wide variety of recreational facilities, marginal reclamations for nature reserves or limited agriculture, housing facilities in the Flintshire foothills and industrial development south-east of the present estuary head could all be compatible with a multi-purpose estuary scheme; other than navigation interests - see (xi) above - the crux of compatibility rests upon far-reaching decisions as to the type and siting of industry on the Flintshire shore or on reclamations;
- (xxi) benefits, even from staged schemes, should not be expected to start accruing under normal procedures for 6-9 years, say, until 1976 (1.3.10 (a) and drawing 18);
- (xxii) recommendations for Phase II are contained in appendix B7 and include proposals for: hydraulic model tests; a full-scale origin/destination traffic survey and subsequent study; more site investigations; various large-scale tests on stabilizing sand foundations and forming embankments, also in connection with estuary reservoirs (further tests for leakage and water quality); pilot studies on water treatment; special studies on amenities, landscaping and on land use including use of an estuary scheme to meet recreational demands; salmon fishery research; hydrological studies including river gauging; mathematical model study; air and land surveys; sundry interim reports as required (in preference to awaiting consolidated report at end of Phase II).

## 1.5 DECISION SEQUENCES

It was felt to be useful, by the Ministry of Land and Natural Resources and by the respective Chairmen of the Steering and Working Party Committees, to include suggested sequences of decisions which might be taken during consideration of the report; such a sequence might be to decide:-

- (i) whether any of the proposed estuary schemes merit proceeding to a next phase (a) now (b) later or (c) never - if (b), planning and transport authorities would clearly need an indication of the likely deferment period and, if (c), they would wish to decide whether a single-purpose, "head of the estuary" future crossing and approaches should be contemplated in due course to resolve the Queensferry problem;
- (ii) whether consideration of tidal power aspects should continue to be excluded from the terms of reference;
- (iii) whether all outer line schemes can be eliminated now;
- (iv) whether single-purpose pure bridge crossings are (a) the only schemes to be pursued (b) to continue to be considered (broadly or in full detail) or (c) to be discarded;
- (v) whether the multi-purpose, staged schemes (types X to Z) are to be reduced and refined, after comment and further study, to give a choice from only a few specific schemes of this type;
- (vi) whether enough has been done in Phase I not only to establish practicability but to assess the likely order of social and economic benefits; hence whether Phase II should be directed towards defining and choosing a scheme for seeking Parliamentary powers, during which process, the usual further detailed investigations and designs could be continued;
- (vii) how further work on a Dee estuary scheme should be financed; how much money for a scheme is likely to be provided/should be requested;
- (viii) what authority, joint committee or other body should be formed to seek powers, guide and administer the work and, in due course, operate the scheme;
- (ix) whether amenity features such as a mere on the Wirral shore are required and would finance be forthcoming for their early provision;



- (x) whether the industrial nuclei on the present Flintshire shore will be planned to expand as nuclei or as a continuous belt or not at all; whether Flintshire will aim towards having its own "amenity" shore-line, at least in part by clearing up in time the old legacy of industrial development; whether future industrial expansion will be on reclamation or set back from the coast, for example, in or near the existing complex at the estuary head; whether certain forms of modern industrial architecture and development could be specifically arranged on certain estuary lands, not only to be compatible with amenity but to enhance an over-all plan;
- (xi) whether estuary schemes would create a need for some form of joint planning; whether the estuary and its environs are to be regarded as a regional and national asset for amenity, recreation and improved living standards with coherent development of all aspects;
- (xii) depending upon the above, which other planning authorities and interested parties should be kept informed of the likely scheme(s) and the implications, with a view to exchanges of information and in the interests of co-ordination - there are too many to list here but it would be well worth deciding upon how this co-ordination could be achieved without involving large and time-consuming committees;
- (xiii) again, depending upon the above, which of the suggested requirements for Phase II in appendix B7 are relevant and when they should be implemented.

1.6 ACKNOWLEDGEMENTS

The active help and encouragement of the Technical Working Party and of the Steering Committee - most of whom some members of the study team managed to meet - have been invaluable and greatly appreciated. The many individuals concerned and all other authorities and bodies listed in appendix B2 are also thanked for their help and interest, especially those who have done much work in contributing data.

2.1 INTRODUCTION

It is assumed that most readers, having been introduced to the proposed schemes and being aware of the conclusions in part 1, will wish next to read one or more of the chapters in this part which give appreciations on various special aspects of Dee estuary development potential. Those, however, who are unfamiliar with the area may wish first to refer to regional studies <sup>53, 54, 55</sup> \* or to read appendix E2 on urban and industrial development. Others, again, may prefer to gain fuller understanding of the proposed schemes by reading the appraisals in part 3. Parts 4 and 5 and most of the appendices are broadly for the more specialist reader.

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\* reference numbers throughout the text are not consecutive due to the arrangement of the list of references in appendix B5.

## 2.2 COMMUNICATIONS

### 2.2.1 Existing primary road system

(a) Having afforded to travellers over the centuries the first crossing of the Dee near its tidal limit, Chester has an historical significance as a gateway to North Wales. Until 1925 no road crossing existed below Chester nor for some ten miles upstream, so that there grew up a system of major highways converging on Chester from all directions (drawing 1). The focus of this system since the fourteenth century has been the single-lane Old Dee Bridge, augmented in 1832 by the two-lane Grosvenor Bridge a quarter of a mile downstream.

(b) It is easy to picture the congestion that developed in the streets of Chester with the growing use of motor vehicles in the present century. In 1925, long after the channelling of the Dee below Chester had enabled land to be reclaimed in the upper estuary, the situation was somewhat relieved by the building of a two-lane bridge at Queensferry, some six miles downstream of the city.

(c) For thirty-seven years, this bridge gave the only relief from congestion in Chester due to cross-Dee traffic until it was itself augmented in 1962 by a new dual-carriageway bridge slightly upstream.

(d) South of the Dee in Flintshire, the new Queensferry Bridge is connected at once to the Flintshire coast road A. 548 from Chester to Rhyl and, by route A. 494, to the A. 55 which, radiating north-westwards from Chester via Holywell and St. Asaph, forms the chief route to North Wales. The A. 550 continues southwards from Queensferry towards Wrexham.

(e) In Cheshire the new Queensferry Bridge is connected directly by routes A. 550 and A. 5117 to the A. 41 north of Chester (leading to Birkenhead and, via the Mersey road tunnel, to Liverpool) and to the A. 56 which radiates north-eastwards from Chester towards Manchester, giving access to crossings of the Mersey at Runcorn and Warrington.

(f) Thus Chester today can be by-passed to its west and north by traffic between North Wales and the Liverpool and Manchester areas and by traffic between Wrexham and Liverpool, this combined traffic now converging on Queensferry instead of Chester.

(g) Other important roads in the region are the routes A. 51, A. 54 and A. 556 which radiate from Chester to the east and south-east with important interchanges to the Motorway M. 6. Chester can also be by-passed to the east via the A. 41 (which here forms the first section of the

## 2.2.1 Existing primary road system (cont'd)

Chester Outer Ring Road) by traffic from the south and east to Merseyside and Ellesmere Port. North Wales traffic from the south and east of Chester, however, is still drawn through Chester itself.

(h) Traffic flows on many other existing primary roads in the region, several of which also radiate either from Chester or Queensferry, would be affected by an estuary crossing. Among these are the routes A. 540 from Chester to West Kirby, A. 494 from Queensferry via Mold to Ruthin and A. 541 beyond Mold to St. Asaph branching via the A. 543 to Denbigh.

(j) The motorway M. 6, now the chief north-south traffic artery through the region, is especially relevant to the present study. For traffic between North Wales and the North of England and Scotland, it provides a crossing of the Mersey some four miles east of Warrington, as an alternative to the route via the present tunnel and Liverpool. The superiority of this alternative route should be more marked after completion of other major roadworks in Cheshire (drawing 1).

## Proposed new roads and improvements

(k) While much thought has been given in the past to a possible crossing of the Dee estuary, current road improvements clearly could not take this into account due to the uncertainties of location and timing and, indeed, of the many other implications of a crossing.

## North Wales

(l) The highway situation west of the estuary, in Flintshire and Denbighshire, is seen to be mainly one of improving and maintaining the major corridor routes between the present crossings at Queensferry and Chester and the North Wales holiday resorts. Thus in Flintshire the chief aim of the present road programme is improvement of the A. 55 from Chester to Bangor and the coast road A. 548, including a long-term proposal to widen the new Queensferry by-pass. These improvements include by-passes at St. Asaph (starting in 1967), Hawarden and Holywell on the A. 55, and at Bagillt and Ffynnongroew on the A. 548.

(m) Other proposed improvements in Flintshire concern routes A. 494 and A. 550, radiating south and south-west from the new Queensferry Bridge, and the eventual improvement of the A. 541 both to the south-east and to the north-west of Mold. Completion of the Chester Outer Ring Road by extension into Flintshire will also be important.

### 2.2.1 Existing primary road system (cont'd)

- (n) Further west in Denbighshire, work is due to start early in 1967 on the construction of a by-pass to Abergele on the A.55.

### Cheshire

- (o) The two existing main roads along the Wirral (the A.41 serving the urban industrialised eastern strip of the peninsula and the A.540 from Chester to the urban residential western side) are both now overloaded during peak hours. Their improvement is planned but is limited by roadside development.

- (p) Intensive commuter traffic across the Wirral peninsula uses routes A.551, A.552, A.553, A.5027, B.5136 and B.5137 between the residential west side and the Merseyside conurbation. Lengths of these roads are also overloaded now at peak hours and their improvement is planned within the next ten to fifteen years.

- (q) Much of the traffic along and across the Wirral converges on the existing Mersey road tunnel between Birkenhead and Liverpool, causing severe peak-hour congestion. Work has recently started on a new road tunnel between Wallasey and Liverpool. Opening of the first tube of the new tunnel in 1970 is expected to coincide with completion of the proposed Mid-Wirral Road extending from the new tunnel around the outskirts of Birkenhead and southwards along the Wirral, to join the A.41 south of the A.5117.

- (r) An early start is to be made on the proposed Hooton Industrial Road, which will join the Chester Road (A.41) near Hooton, to Ellesmere Port and extensions to this are under consideration westwards to connect with the proposed Mid-Wirral Road, and south-eastwards from Ellesmere Port to the A.5117 near Little Stanney.

- (s) Sections of the two existing trunk routes A.56 and A.556 between west Cheshire and Manchester are now severely overloaded and the Minister of Transport has recently authorised work to start on the North Cheshire East-West Motorway. The first section of this motorway between the junction of the A.56 and the A.556 at Millington and Manchester (Princess Parkway) is due to be started in 1967/68. The second section between the A.5117 near Hapsford and the A.56 north of Preston Brook, which will provide a by-pass to the Helsby-Frodsham area, is due to be started in 1968/69. Completion of the section of motorway between the first two lengths, including an interchange connection with the M.6, is expected to follow within ten years. Westwards from Hapsford proposals have been made for extending the East-West Motorway towards Queensferry.

## 2.2.1 Existing primary road system (cont'd)

(t) Construction of the southern section of the Chester Outer Ring Road between the A. 41 and the Wrexham Road (A. 483) is expected within the next ten years, it being envisaged that the extension westwards to join the A. 55 near Broughton in Flintshire would soon follow.

(u) Other proposed major road improvements in West Cheshire concern the routes A. 483 (Wrexham Road), A. 41 (Whitchurch Road) and A. 51 radiating south and east from Chester, route A. 54 eastwards from the A. 51, including by-passes to Winsford and Middlewich and route A. 534 from Wrexham to Crewe. A new road is also proposed by Cheshire County Council to connect the proposed North Cheshire East-West Motorway near Hapsford, southwards to the A. 56 and thence to the Chester Outer Ring Road.

## Liverpool and South Lancashire

(v) Since it was opened in 1961, the single carriageway (three-lane) road bridge across the Mersey between Widnes and Runcorn has provided the nearest alternative crossing to the present Liverpool-Birkenhead tunnel, discounting the vehicular ferries between Liverpool and both Birkenhead and Wallasey. The second tunnel crossing is mentioned earlier (paragraph 2.2.1 (q)) and a possible third road crossing in the Merseyside conurbation area is referred to in paragraphs 2.2.2(c), (p) and (q).

(w) North of the Mersey, improvements are proposed by 1982 to several major roads which now carry traffic between North Wales and the North of England and Scotland. Some of these improvements in Liverpool itself are planned in conjunction with approaches to the second Mersey tunnel.

(x) Construction of a new urban motorway system within Liverpool (the Inner Motorway and the North-South Primary Motorway) is also envisaged, together with improvements to Queen's Drive (the existing Liverpool Ring Road) and to several major radial routes converging on the centre of Liverpool. Among these latter, extending into Lancashire and beyond, are the route A. 565 northwards through Bootle and Crosby to Southport, route A. 59 north-eastwards to Ormskirk and Preston and the East Lancashire Road (A. 580) eastwards to Manchester connecting with the M. 6.

(y) Also relevant are motorway proposals in Lancashire, expected to be completed by 1982. These include an outer ring road around Liverpool from Thornton in the north to join the recently completed Speke-Widnes Link Road (A. 562) in the south and the proposed South Lancashire Motorway from Liverpool to Manchester which will also connect with the M. 6.

### 2.2.2 Traffic studies

(a) The results of the following extensive traffic surveys and studies in the region have been taken into consideration :-

#### Flintshire traffic surveys

(b) In an attempt to assess the volume of traffic that would use a crossing of the Dee, the Flintshire County Surveyor instituted an origin-destination survey in August and October, 1961 by means of reply post-card questionnaires with a detailed traffic count by classification of vehicles. The survey points north of Queensferry on routes A. 550 and A. 548, and south of Queensferry on route A. 55, were chosen to omit traffic with origin or destination so close to Queensferry or Chester that it would not benefit by a new estuary crossing.

(c) Later traffic counts have been made by Flintshire for both of the Queensferry Bridges from April to August 1962 and, in August 1966, throughout Flintshire on all main roads, including both Queensferry Bridges and their approaches.

#### Cheshire traffic surveys

(d) The report of January, 1965 by the Cheshire County Surveyor on the North Cheshire East-West Motorway contains origin-destination statistics for traffic originating in North Wales and passing through Cheshire with lines showing traffic desire in and through the county in 1962. This information is built up from a number of traffic surveys carried out in Cheshire and neighbouring authorities including the S. E. L. N. E. C. Survey of 1960, the South Lancashire Motorway Survey of 1962, the Cheshire East-West Survey of 1962, the Chester Ring Road Survey of 1962 and the Merseyside Conurbation Survey of 1962.

(e) The results of the Ellesmere Port Traffic Survey of 1965 have also been made available by the Cheshire County Surveyor.

#### Merseyside conurbation

(f) The report of the Highways and Traffic Committee of June 1965 to the Merseyside Traffic and Transport Steering Committee, describes the comprehensive traffic survey which was undertaken in 1962 throughout the Merseyside conurbation, including the whole of the Wirral peninsula north and east of Neston, as well as Liverpool, Bootle and part of south-west Lancashire. This was a standard origin and destination survey by direct roadside interview at all census points except at the entrances to the Mersey tunnel, where post-card questionnaires were issued to minimize interviewing delays.

Mid-Wirral road study

(g) A comprehensive study of traffic flows through the Wirral, including cross-Mersey traffic flows, was undertaken during 1965 / 66 in connection with a report to the Minister of Transport on the Mid-Wirral Road <sup>25</sup>. This study was based on information from the Merseyside Conurbation traffic survey of 1962 and the Cheshire surveys referred to above.

Cross-Dee traffic flows

(h) The first step in assessing traffic flows across the Dee has been to adopt a series of dates for relating population and car-ownership data and traffic predictions. The census years 1981 and 2001 were chosen and it was convenient to adopt as the datum year 1962, the date of the traffic counts at Queensferry.

(j) Data already available warranted a theoretical traffic flow study by gravity model, the results of which are regarded as accurate enough for having recommendations and decisions in Phase I of the study. While the gravity model is an acceptable tool for this purpose provided that its limitations are understood, in Phase II a full-scale origin and destination survey would be essential for evaluating traffic flows more precisely.

(k) The Phase I gravity model procedures and results are described in appendices C1 - C4. The model depends for its calibration upon an acceptable base flow derived from actual counts of traffic flow across the bridges at Queensferry. Since the link in the model across the Dee at Queensferry represents both the old bridge with its approaches and the new by-pass, it was valid to sum the flows on the two bridges. The automatic 24-hour traffic counts over the Queensferry bridges from April to August 1962 showed a large daily fluctuation (figure A in appendix C2). The heaviest flows were at weekends and statutory holidays and comprised mainly tourists and holidaymakers as, indeed, applies to traffic to and from North Wales over most of the year.

(l) In recent years there has been growing recognition that tourists and holidaymakers are important road users in their own right and should receive due consideration in the design of new highways. With this in mind but discounting the weekend and statutory holiday peaks, a representative 24-hour flow of 28,500 vehicles (two-way) for the two existing Queensferry bridges in the summer of 1962 has been adopted as a base flow for the traffic model studies.

### 2.2.2 Traffic studies (cont'd)

(m) While this figure is somewhat above the corresponding out-of-season daily flow during 1962 (e.g. a 24-hour flow of 20,000 vehicles for April) it is nevertheless well below the peak daily flows at weekends and on holidays. As the figure in appendix C2 shows the 24-hour flows during the Easter weekend of 1962 approached 45,000 vehicles.

(n) Congestion at Queensferry since the opening of the new bridge and by-pass has been due not to lack of capacity in the bridges but to the inadequate junctions and approaches beyond each of the bridges, particularly south of the Dee where three main roads converge. This problem is discussed later in this section.

### Influence of Mersey road crossings

(o) A problem in traffic estimating was posed by the degree of peak-hour congestion in the adjacent Merseyside conurbation area and, in particular, by the physical constraints on free traffic flow across the Mersey. A crossing of the Dee estuary would have important traffic repercussions in the Merseyside conurbation area. Conversely the degree of overloading of Mersey crossings, calculated on the combined capacity of both existing and new crossings, was held to be a restraint on free flow on a Dee estuary crossing. The manner in which this restraint is applied to traffic flows across the Dee is described in appendix C3.

(p) Earlier studies<sup>24, 25</sup> have confirmed that, to cope with peak-hour flows expected by 1982, a third Mersey highway crossing will be needed in the conurbation area to augment the existing tunnel and the new Wallasey - Liverpool tunnel. The question of what, if any, future road crossings should be provided is beyond the scope of this study but clearly the effects on traffic flows across the Dee have had to be gauged by testing the system with and without a third Mersey Crossing.

(q) During the traffic studies for the Mid-Wirral Road it was ascertained that a third road crossing of the Mersey near the existing and new tunnels would be unacceptable because the total cross-Mersey traffic in the approaches to three adjacent crossings could not be collected and dispersed satisfactorily. A traffic assignment showed that a crossing between New Brighton and Bootle could not be justified by resultant traffic flow estimates. Thus it was assumed that any third Mersey road crossing within the conurbation area would be south of Birkenhead, between Port Sunlight and Bromborough. The precise location within this reach of the Mersey is immaterial to this study.

Queensferry

(r) The measured traffic flows across the Dee at Queensferry in the summer of 1962 show that, notwithstanding the opening of the dual two-lane by-pass early in that year, the two-lane Old Queensferry Bridge continued to carry a relatively high proportion of the daily cross-river traffic flow. In April this proportion varied from over 50% on a normal (mid-week) day to about 35% during the Easter week-end and in August it varied between 30% and 45%.

(s) At the Old Bridge and approaches, the maximum capacity now is probably no more than a daily (16-hour) flow of about 15,000 v.p.d. (two-way).

(t) Conditions on the new by-pass bridge correspond with those of an urban all-purpose road and its present maximum capacity is likely to be about 2,400 p.c.u. per hour in each direction, equivalent to a maximum daily (16-hour) flow of about 40,000 v.p.d. (two-way).

(u) The cross-Dee traffic capacity at Queensferry could be increased by controlling waiting and providing lay-byes on the approaches to the Old Bridge but the combined daily (16-hour) capacity would still be unlikely to exceed 60,000 v.p.d.

(v) From the estimates of cross-Dee traffic at Queensferry made in this study, with no estuary crossing it might seem that the two bridges could be made to suffice until about 1980 in the absence of a completed Chester Outer Ring Road, or until about 1985 if the Ring Road were completed meanwhile. However, as has been mentioned earlier, congestion already occurs at peak hours, due to the inadequacy of the connections of the bridge approaches with other roads both to the north-east and south-west sides of the river. Thus in order to improve conditions for traffic crossing the Dee at Queensferry, it seems that priority should be given to improving the layout and design of the connections of the A.550 with both the A.5117 and A.548 north-east of Queensferry, and of the connections of the A.494 and A.550 with the A.548 at Queensferry, and of the A.494 and A.550 with the A.55 south-west and south of Queensferry.

(w) It is most doubtful whether the capacities of these connections could be raised enough to take full advantage of the potential capacity of the Queensferry river crossings. Multi-level free flowing interchanges would be needed, entailing high cost and much property acquisition. More realistic improvements would still leave their traffic capacities short of those of the river crossings themselves. As an indication, expenditure of some £2½m. on improvements to these connections,

### 2.2.2 Traffic studies (cont'd)

completed by 1971, might relieve congestion only until about 1976 without the Chester Outer Ring Road or until about 1981 if it were completed meanwhile.

#### Chester Outer Ring Road

(x) For the purposes of the gravity model it has been assumed in this study that the proposed Chester Outer Ring Road will be in operation throughout its length by 1981. The study has shown that by that year the Ring Road would attract some 10,000 v.p.d. away from Queensferry in the absence of an estuary crossing, but that the Ring Road itself would lose some 10,000 v.p.d. to an estuary crossing completed by 1981. The distribution of cross-Dee traffic between estuary crossings, Queensferry, Chester Road and the Outer Ring Road is given in the tables in appendix C4 and is illustrated on drawings 10 to 12.

#### Chester

(y) The effect of an estuary crossing on the flow of North Wales traffic through Chester is likely to be of little significance, as will be seen from the tables and illustrations; this is held to be so, whether or not the Chester Outer Ring Road is constructed first.

### 2.2.3 Alternative crossings of the estuary

(a) Many crossing alignments from the mouth to the head of the estuary were studied and found to be feasible from purely highway engineering and planning criteria applied to the road approaches.

(b) On drawing 1, only those alignments which merited more detailed study are indicated. Alternatives shown in full line represent links inserted in the gravity model in turn, either separately or in different combinations, while those in chain dotted form represent feasible alternative alignments and approaches. The approach road routes are not described in the text since the alignments are only diagrammatic at this stage.

(c) The various crossing locations fall broadly into three zones :-

- (i) the inner zone is at the upper end of the estuary where a single crossing, in its simplest form, would be solely a road project and would form a localized by-pass to the Queensferry - Shotton - Connah's Quay area. Common to all inner zone alignments is a terminal point (B) (at the present junction of the A. 5117 with the A. 550) near Shotwick.

## 2.2.3 Alternative crossings of the estuary (cont'd)

On the Flintshire side, an alternative approach road CD would have rather steeper gradients than would AF (or more earthworks costs with similar gradients);

- (ii) the middle zone is broadly enclosed between lines from Bagillt to Neston and from Mostyn to Thurstaston. It includes alternative alignments studied in some detail roughly corresponding to the so-called Greenfield - Gayton and Greenfield - Thurstaston lines. In Flintshire approach road HU would be steeper than HN or would entail more earthworks with similar gradients;
- (iii) the outer zone extends seaward from the Mostyn to Thurstaston line. Of several routes studied for a crossing in this zone, QP was finally adopted for the gravity model.

At the time of the Mid-Wirral Road study, it had emerged quite clearly that the planned highway system which was envisaged at the northern end of the Wirral in the 1980's could not be given enough capacity to cope with North Wales traffic funnelled directly from a Dee estuary crossing into Wallasey or northern Birkenhead. It has been established that the problems of congestion will be particularly acute, not only at the existing Birkenhead - Liverpool road tunnel and at the new Wallasey - Liverpool tunnel, but also at their approaches on each side of the Mersey. For this reason alone a proposal that would encourage all cross-Dee estuary/cross-Mersey traffic to try to use these tunnels, by connecting an estuary crossing to the planned road network in the northern part of the Wirral any further north than the proposed Woodchurch Road interchange (P), is undesirable. Hence no approach alignment north of West Kirby has been investigated.

### Traffic assignments

(d) The highway network of the gravity model as adopted for 1981 was amended for successive computer runs by substituting different links (drawing 1) to represent :-

- (i) inner zone crossing AFB;
- (ii) middle zone crossing HNJK (for schemes W, X or Z);
- (iii) outer zone crossing QP;
- (iv) middle zone crossing HNJK plus inner zone crossing FB, with a new road link NUDE alongside the Flintshire shore (for schemes XX or ZZ);
- (v) combined middle and inner zone crossings HNUDEB, with a spur road EG (for scheme Y).

## 2.2.3 Alternative crossings of the estuary (cont'd)

(e) After study of the 1981 traffic flow estimates and benefits, flow estimates were not made for other years with single crossing arrangements (i) or (iii) above. For arrangements (ii), (iv) and (v) and for the no-crossing condition, flow estimates were made for 2001 but with the highway network remaining as for 1981, since no information was available about road-development plans thereafter. For comparison, similar estimates were made for the 1962 traffic volumes using the "1981 highway network".

(f) In all the arrangements described for 1962, 1981 and 2001, traffic flows were obtained first assuming the existence of a third Mersey crossing in the network. The flows were then adjusted to take account of conditions without such a crossing and it is upon these results that economic benefits of a Dee estuary crossing are calculated. (The increased benefit of about 10% with a third Mersey crossing would be one of the benefits accruing to investment in a third Mersey crossing built after a Dee estuary crossing).

### Traffic flows and desire lines

(g) Tables 1, 2 and 3 of appendix C4 contain the results of the traffic flow estimates for 1962, 1981 and 2001 respectively. Table 2 also includes the results of a separate toll crossing assignment referred to in appendix E4. Table 4 contains the results for 2001 assuming an extra 200,000 people in North Wales. Estimates are given, in vehicles per 16-hour day, of traffic generated by and diverted to an estuary crossing or crossings. Savings in vehicle miles and vehicle hours are also tabulated.

(h) Linear interpolation has been used in chapter 5.2 in assessing highway capacity requirements for the crossings and approaches at any time.

(j) Drawings 7 to 9 show the cross-Dee desire lines, including generated traffic (with specific estuary crossings) in the three reference years, the desires being represented by straight lines between the origins and destinations, the width of the desire lines representing the estimated desire.

(k) Traffic flows for alternative crossings (and for no-crossing) assuming a third Mersey crossing, are shown to scale for each reference year on drawings 10 to 12. The residual distribution of traffic over existing crossings of the Dee at Queensferry and Chester is also shown.

### 2.2.3 Alternative crossings of the estuary (cont'd)

#### Benefits and costs of highway crossings

- (b) Benefits are compared with costs of pure crossing schemes and of crossings within multi-purpose schemes in part 3.

### 2.2.4 Railways

- (a) The possibility has been explored of incorporating a railway crossing of the Dee estuary in a highway crossing scheme but, from discussions held, it is clear that the British Railways Board have no proposals for a cross-estuary link.
- (b) The Flint/Queensferry area now has rail access to Merseyside, either through Chester or by the Wrexham to Birkenhead line (via Shotton and Bidston) on which, however, the Railways Board has announced its intention of discontinuing passenger services due to the low demand.
- (c) The case for an estuary rail crossing would depend largely upon a high future passenger demand unless the present low demand for goods haulage by rail from North Wales to Merseyside also increased quite exceptionally. The volume of traffic, however, which an estuary rail crossing would generate and attract in the form of "transferred" traffic (i.e. from road to rail) cannot be predicted with any assurance.
- (d) Enquiries have been made of British Railways as to the feasibility of various rail links considered, especially that of extending the line between Birkenhead and West Kirby across the estuary to link up with the North Wales line at Point of Air. By affording the greatest time saving to holiday makers and would-be commuters to the Merseyside area, this link would probably be the most used and might be thought profitable, given the added incentive that the formation widths for a railway could be added cheaply to a highway embankment or barrage. Even so the most optimistic forecasts of returns from rail traffic could not be expected to offset the other disadvantages of an outer line scheme (see part 3), nor could it be envisaged that the link would in effect be subsidized for over-all transportation reasons to such an extent.
- (e) Across the middle or inner zones of the estuary, the demand for a rail link might well decrease because of the reduced saving in journey time or cost, while the railway capital and running costs would be greater, particularly since a connection to the Shotton - Bidston line could scarcely be commended, while the line south of West Kirby has now ceased to exist.

#### 2.2.4 Railways (cont'd)

(f) Thus it seems that further study of an estuary rail link would be unjustified unless :-

- (i) economic growth in North Wales (population, industry and holiday facilities) were expected to increase much more quickly than has been assumed;
- (ii) an outer zone scheme were to be pursued for reasons not now apparent;
- (iii) commuter rail traffic for distances of 15 miles and less became economic to operate or merited subsidy;
- (iv) again, for some reasons not now apparent, a cross-estuary rail link enabled economies to be effected by foregoing other services and by recouping revenue losses due to shorter journeys.

#### Road/rail interchange in the Wirral

(g) The problems of highway congestion in the Mersey crossings and conurbation have been mentioned in earlier sections. On the other hand, recent reports have described how the capacity of the Mersey rail tunnel could be almost doubled from the present 8,650 seated passengers per hour to 14,320 per hour in each direction for a cost of some £2.75m<sup>25</sup>. In view of the grave doubts as to the viability of a direct rail link across the Dee estuary, a road/rail (rapid transit) interchange between the Wirral approach to a Dee road crossing and the existing railway system leading to the Mersey rail tunnel has been considered in this study as a possible contribution to a co-ordinated transportation plan for the conurbation area. (If the time and total cost to the traveller between the road/rail interchange and central Liverpool were no more by rail than by road, some of the peak hour cross-Mersey traffic might be encouraged to divert in effect from the road tunnels to the rail tunnel). The interchange would have to be designed with adequate parking capacity close to an existing railway line but not necessarily adjacent to an existing station.

#### Possible locations

(h) In conjunction with approach road alignments to Dee estuary road crossings, three possible interchange locations have been investigated: near West Kirby, the Woodchurch Interchange on the proposed Mid-Wirral Road (point P on drawing 1) and near Heswall Hills station east of Gayton. The third location seems most promising from space and planning considerations and would best suit highway crossings in the middle or inner zones, rather than in the outer zone, of the estuary.

#### 2.2.4 Railways (cont'd)

(j) Whereas at peak hours the railway from West Kirby is now running nearly at capacity with present facilities, the line from Neston to Birkenhead is little used by passengers and British Railways have recently notified their intention to withdraw their passenger services from this line (paragraph (b)). Thus a road/rail interchange near Heswall Hills station might entail a review of policy decisions already taken.

(k) The development of road/rail interchange proposals is best deferred until Phase II of the Dee study, before completion of which the Merseyside Area Land use/Transportation Study results should be available for guidance. Regardless of the locations of the Dee crossing and of its connection with the Mid-Wirral Road, a good case may well be made for the provision of extensive parking facilities at several locations in the Wirral in order to attract to the railway more commuters from the Wirral generally and not merely those crossing the Dee by road. If so, a car-park east of Gayton would have to accommodate not only the cars of cross-Dee commuters or visitors to Liverpool but some commuters from adjacent areas of the Wirral.

#### 2.2.5 Navigation and ports

(a) Mostyn is the only port in the Dee estuary. It is operated by the Mostyn Docks and Trading Company, a subsidiary of Thos.W. Ward Ltd. There are two quays, one 510 ft long and the other 220 ft at which vessels up to 285 ft can be berthed. The harbour dries at low water but the depth is 20 ft at high water springs. An entrance channel or gutter was dug through the foreshore to deep water in the estuary. It is maintained by flushing at low tide from reservoirs which fill at high water. There is now deep water at the end of the mole of slag which extends alongside the gutter half a mile from the shore. Hydraulic model tests would show whether this situation could be maintained if works were carried out in the estuary.

(b) The return on the capital now being invested in development at Mostyn and the life of plant and facilities are such that a developing estuary scheme might not affect the port's viability even if it were to turn over to container traffic. On the other hand, an outer line scheme would probably have such a rapid effect on the approaches to the port that a large increase in business would be needed to offset the cost of maintaining the navigation.

(c) Charts since 1649 show a deterioration in the navigable channels of the estuary. Attempts have been made to stabilize the channels and to maintain the depths but the main anchorage in the estuary has moved down from Chester first to Shotwick, then to Old Quay, Parkgate, Caldy

## 2. 2. 5 Navigation and ports (cont'd)

and now to Mostyn. After the Dee was trained along the Welsh shore, Connah's Quay and Flint were used as harbours. Today both are derelict, although coasters still work the tides to the steelworks of John Summers & Sons Ltd.

(d) Extension of the river training works to the deeper water off Greenfield would improve the navigation above this point but the cost would not be justified for the size of vessel that could use the channel.

(e) Schemes which include water conservation would keep the river in the canalized section at about the present low water level (chapter 5. 5) with gates to keep out the sea. These would be below Oakenholt and, although a lock would be provided for small fishing vessels and pleasure craft, sea-going trade would be precluded.

(f) Documented experience in the Lune<sup>84</sup>, Wyre<sup>84</sup>, Mersey<sup>87</sup> and the Wash<sup>85</sup> supports observations and model tests of the Dee estuary<sup>86, 99, 112</sup> that shoaling occurs to seaward of training works. Shoaling is worse if there is also reclamation. The hydraulic model would show how far reclamation could extend down the estuary before the port of Mostyn was affected (see part II of appendix B1).

(g) The volume of water that flows in and out of the estuary with each tide (the tidal cubature) would be reduced by all engineering works except a full length bridge. A large reduction in the cubature caused, for example, by an outer zone scheme would have a pronounced effect on the channels leading to the estuary. The hydraulic model has a fixed bed to seaward of the outer zone and, while accretion may be modelled, changes in the position of the deep channels cannot be predicted by the present model. Experience suggests, however, that the depths in the Inner Channel leading to the Welsh Channel and Hilbre Swash would eventually be reduced so that, even if enough water could be maintained off Mostyn itself, dredging would be required further out to sea.

(h) The Welsh Channel has been a stable feature of the estuary mouth at least since the date of the early charts. While there is enough depth locally for the largest hulk carrying vessels such as tankers and ore carriers, the creation of deep water berths off the Point of Air is most unlikely, since this would depend upon continuous and extensive dredging being found to be worthwhile.

(i) No appendix giving data or valuations on navigation and ports is provided pending results from hydraulic model tests. These aspects should comprise an early interim report in Phase II.

## 2.2.6 Air

(a) By an Act of Parliament in 1961, responsibility for all airports with the exceptions of Heathrow, Northolt, Gatwick and Prestwick, was transferred to the local authorities. The operation of the four exceptions was put in the hands of the newly constituted British Airports Authority, by whom the study team were referred to the Board of Trade who retain a measure of control as the planning authority for all municipal and national airports. The views of the Board of Trade were therefore sought about the possibility of developing a new airport on reclaimed land in the Dee estuary.

(b) Until 1985 at least, all foreseeable traffic from the North West and North Wales can be handled by the existing airports at Ringway and Speke, which are now much under-used. Hawarden is used by a small number of passengers (some 14,000 in 1964 compared with Speke 350,000+ and Ringway 1,000,000+). The present unattractive journey to Speke from North Wales and the Wirral may well be encouraging people to use Hawarden, so that future use of this airport cannot be estimated reliably. The life of the airfield, which is owned and operated by the Hawker-Siddeley Group, is bound up with that of the aircraft industry. If they gave up the airfield, it is difficult to see who else would be prepared to take it over on a commercial basis.

(c) For international flying, land has been reserved at Ringway for a runway 12,000 feet long for planes of the future making non-stop flights to San Francisco. At Speke the present runway length of 7,500 feet can be extended to 10,500 feet and, if a third Mersey crossing were built near Bromborough, this airport would become much more easily accessible from North Wales and the Wirral. The region is therefore well catered for and it is unlikely to need a third major airport within the next two decades.

(d) In short, only developments at Manchester and Liverpool airports are expected in the foreseeable future. Beyond 1985 an alternative airport may require consideration. Until the need for this can be more clearly assessed, it might be wise to protect some areas of the Dee estuary from development of a type that would weigh against the siting there of a major airport.

## 2.3 WATER CONSERVATION

### 2.3.1 Hydrology

(a) The hydrology of the Dee is discussed in appendix D1. The average natural flow to the sea is estimated to be nearly 800 mgd. Normal economic use of a river basin suggests that a reliable yield of 400 to 500 mgd should be available. Present authorized or licensed abstractions of 117 mgd include exports from the catchment of some 100 mgd, using a direct supply reservoir and two regulating reservoirs near the headwaters providing 19,000 mg of storage.

(b) A further 50,000 mg of storage are required to provide an additional reliable yield of 300 mgd and a compensation flow of 70 mgd. While some potential upland reservoir sites exist they could provide only a small part of this capacity. Estuary storage would have to be used for such a development, especially as the whole catchment run-off would be needed to refill the storage after a dry period.

### 2.3.2 Demand

The Water Resources Board are advising upon the allocation of water resources to specific areas of demand but their work is not complete and indeed it depends upon extensive studies of all the resources. Failing an exact knowledge of the area to be supplied, various rates of increase of demand have been examined each corresponding to an assumed population supplied. Details are given in appendix D2. Rates of 5 and 10 mgd per annum have been used as indicators in subsequent work. They correspond to a total increase of 300 mgd in 60 and 30 years to meet the needs of present day (1966) populations of 3 and 6 millions respectively. Populations of this order exist in regions adjoining the estuary which have been termed the natural area and the extended area of supply in this report. For present purposes it has been assumed that existing resources in these areas would be fully committed by the year 1976 or soon after.

### 2.3.3 Works

(a) Storage fed by gravity could be provided by constructing a barrage across the estuary. Alternatively, one or several impoundments with perimeter embankments (bunds) and somewhat higher retention levels could be built, water being pumped into them from a gravity-fed balancing basin.

(b) With gravity storage a top water level lower than the crest of Chester weir (13.85 ft O.D.) would have to be used to avoid increased water-logging of land upstream at sustained high river flows. Indeed, because of the danger of the banks being overtopped downstream of Chester

### 2.3.3 Works (cont'd)

with water backed up the river channel during high floods, + 10 ft O.D. would be the highest usable level. Land drainage downstream of the weir would be permanently affected. Pumps would have to be installed at each sluice to raise the water which presently discharges by gravity at about + 5 ft O.D. at low tide. To avoid pumps, a top water level little higher than + 5 ft O.D. would be allowable. The danger of inward seepage of sea water at critical periods of low storage would militate against a bottom water level below 0 ft O.D. With such levels a mid-estuary barrage would provide storage of only 10,000 to 15,000 mg. A barrage across the lower estuary would be required for the 50,000 mg storage needed to realize the potential of this water resource.

(c) In the lower estuary a crest elevation of 33 ft O.D. would be required for freeboard, to avoid more than occasional overtopping by waves and salt spray (chapter 5.1). With gravity storage an excess of freeboard on the reservoir side of 15 ft or more would result, i.e. effectively a waste from the storage viewpoint. Construction costs would be high because of the depth of water (to -65 ft O.D.), the exposed situation and the large volume of tidal flow.

(d) With pumped storage, the retention levels could be chosen to give least cost with regard to height and length of bunds and the expenses of closure, within the limitations of minimum desirable water depth for biological water quality. Freeboard on the reservoir side would generally govern, so the seaward freeboard would be quite generous with less chance of overtopping by salt water. Construction away from the mouth of the estuary in more sheltered and shallower water would be possible, while savings in wave protection on both sides of the embankments would occur because the fetch on the reservoir side could be less. Shallow water could be avoided so that the bottom would be rarely, if ever, exposed on draw-down.

(e) With a working level of + 5 ft O.D. in the balancing basin, existing land drainage would be marginally improved. A basin large enough to balance an extreme coincidence of high river flow and tidal surge could readily be provided.

(f) Pumped rather than gravity storage would not involve expending extra energy on the water supplied. In both cases delivery would ultimately be to high-level service reservoirs. However, the low-lift pumping capacity for taking water from the balancing basin would need to be at least twice the reliable yield to allow for fluctuations in river flow. Thus some extra costs for pumping stations and pumps would arise but these would be quite small.

### 2.3.4 Staged construction

(a) With a rising demand it is important to delay capital expenditure on work not immediately needed and, with a discount rate of 8%, staged construction can yield big economies. In general, increasing the number of stages also increases the total capital cost and there is an optimum number of stages giving minimum discounted cost.

(b) The construction of a barrage to provide gravity storage could not be staged, although two such barrages spaced down the estuary could form stages of a scheme. Because the height of each, however, would be governed by seaward conditions and would be much greater than required simply for storage, a high element of wastage would make them expensive.

(c) Bunded reservoirs could easily be built in stages. A minimum of three stages should be used for the rate of increase in demand and the discount rate used, and some further advantage might be gained by increasing the number to six or even more.

(d) Pumping stations, treatment works and pipelines would all be built in stages. In general, six stages of 50 mgd capacity each have been allowed for but 75 mgd pipeline stages have been used because of the resulting lower present value of capital and running costs in this case.

### 2.3.5 Quality

(a) The water stored in estuary reservoirs would largely originate above Chester weir, near which three undertakings abstract water and have no undue difficulty in treating it for domestic use. Downstream of the weir, however, river inflows include significant sewage and trade effluents. The sewage treatment is being actively improved and Royal Commission standard can be expected in all but one or two minor cases within a few years. Some trade wastes are unsuitable and would have to be diverted through a new sewer discharging into the lower estuary. Increases in effluent quantity by the end of the century are not expected to affect the quality of river water materially, provided that careful control is maintained.

(b) Some increase in the salinity of water stored in estuary reservoirs could be expected. With a water level above mean sea level there would be a net outward seepage and contamination from the sea would not occur. With pumped storage the condition would apply throughout but, under sustained draw-down with gravity storage, seepage flows could reverse. In both cases some diffusion of salt from the reservoir bed would occur during the first few years. It would be less with hunded reservoirs because a slight outward seepage over the whole bed would

### 2.3.5 Quality (cont'd)

oppose diffusion. The chloride content (as Cl) would be unlikely to exceed 50 ppm.

(c) The river water abstracted would contain nutrient salts and, with some added salinity from diffusion in the early years, conditions would be favourable for the growth of algae. However, with the subdivision of storage which could be provided in hunded reservoirs and with two draw-off levels, control measures could be taken and the best water used. This would confer safety and reliability to the supply (section 3, appendix D3). Conventional water treatment would suffice.

(d) Water quality and treatment are discussed in appendix D3 with particular reference to pumped storage. To bring these subjects into perspective it should be noted that the Dee is still a flourishing salmon river and that there are substantial abstractions for water supply at present.

### 2.3.6 Valuation

(a) The difficulties in valuing water are set out in appendix E5. It is concluded that an 'opportunity cost' is the most appropriate measure of benefit. Costs of 30 and 36 pence per thousand gallons (present value) have been taken for alternative supplies for the periods up to and beyond the year 2006 respectively. These costs and those quoted in appendix E9 include for treatment and delivery through trunk mains up to but excluding service reservoirs in the supply areas.

(b) For the natural area of supply a characteristic transmission distance of 24 miles has been taken with a delivery elevation of 300 ft O.D. and for the extended area the corresponding figures are 30 miles and 300 ft O.D.

(c) If further upland storage for the Dee were developed before estuarial storage, the same opportunity cost would apply to the whole development but that accruing to the estuary scheme would be deferred until upland storage had been provided and estuarial storage was needed to develop the full potential of the river basin.

(d) The implications of providing supplies of 300 mgd from the estuary on the development of any small local alternative resources and on the abandonment or transfer of sources are matters for the Water Resources Board, the Dee and Clwyd River Authority and the water undertakings concerned.

## 2.4 AMENITIES, NATURE CONSERVATION AND RECREATION

### 2.4.1 Introduction

The Dee estuary is a national as well as local asset. It is recognized that it has attraction, not only for its scientific interests, but simply for its "wilderness" aspects and the ever-changing visual effects of tidal movement over the shifting sands. Anxiety is already felt, however, about the spread of *Spartina* grass and the accretion on the Wirral side of the estuary, which are destroying quite quickly some of the salt marshes, the bird feeding grounds and the visual amenities.

### 2.4.2 The Nature Conservancy

The Nature Conservancy have kindly contributed a memorandum (reproduced as appendix F1) summarizing the estuary's scientific interest (drawing 13) and the likely ecological effects of estuary schemes. The Conservancy show, amongst other things, a preference for estuary works being well upstream from the estuary mouth.

### 2.4.3 The National Trust

The National Trust would also prefer upstream locations for the estuary works. This is in order to preserve the views from Caldy Hill and Thurston Hill and of those lengths of the Wirral shore still remaining unspoilt by development. They would not favour any approach road to a crossing aligned through the Thurston/Irby area. The local National Trust properties are shown on drawing 13. It is understood that the Trust's properties in North Wales could absorb the greater influx of visitors resulting from easier access over an estuary crossing.

### 2.4.4 Effects of schemes

The proposed multi-purpose schemes (drawings 2 to 6) all allow for a large residual estuary in which a new open coastline of beaches, salt marshes, flats and possibly dunes would form, so that scientific interest over all could be both maintained and diversified, especially if the spread of *Spartina* were prevented from the start. Schemes other than those with the residual estuary along the Wirral shore include the creation of a new "mere" by banks which would be raised later for enclosing higher level lakes for water conservation. This is considered to be a practical way of restoring a water front to parts of the Wirral shore before it is too late. Meres could contain fresh or salt water (by pumping) but the latter might be deemed more suitable for any enlarged marine lake near West Kirby. Water levels in the hunded reservoirs would seldom, if ever, be drawn down to expose unsightly margins.

#### 2.4.5 Recreation

The schemes clearly show great scope for developing recreational facilities from the variety of lakes and meres (and even ponds, for example, in partial 'reclamations' of which some might become nature reserves on the present margins of the estuary). There could be all types of boating (especially sailing and rowing but with power-boating and water-skiing segregated), fishing, swimming, bird-watching and wildfowling. On reclamations there could be golf courses, sports grounds, archery, shooting and various types of clubs<sup>134, 135</sup>. The main point at this stage is to note that recreational considerations would need detailed study in relation both to present resources in the regions and to the engineering of schemes. They would also need careful co-ordination in the light of preserving the scientific interests.

#### 2.4.6 The coastline

(a) Although there is a coastal road on the Flintshire side, estuary views and access are severely limited by the intervening railway embankment and sporadic industrial development. The proposed schemes could change this situation radically, in part by a new coast road beyond the railway and by marginal reclamations. Depending greatly upon over-all planning decisions, there are opportunities for the Flintshire estuary coastline and hinterland to develop a large share of the amenities.

(b) Access to the Wirral estuary coastline, save at West Kirby and Parkgate, is none too easy other than for walkers because roads to the shore, marine drives and other sea-side facilities are few; this is not to suggest that this should be otherwise - indeed, the estuary tidal dangers (quick-flowing gutters, soft muds and sands) are well enough known to have militated against such development which, by now, could have made preservation or renewal of scientific and amenity interests much less significant.

(c) Hence it is clear that any new coastal facilities<sup>2</sup> in the estuary would be expected to differ in type from those provided, for example, by the big resorts in North Wales and Lancashire.

#### 2.4.7 Landscaping and engineering

(a) The schemes are shown deliberately in stylized form in order to generate objective comment; artist's impressions of landscaped views are therefore not provided at this stage. It is important to note, however, that some of the banks would be quite high (drawings 2 to 4) and should

## 2.4.7 Landscaping and engineering (cont'd)

be several hundred yards from the present shore if views are to be maintained; also that, while road embankments would probably be formed in bold lines and curves, certain of the other banks could well be landscaped to good effect, e.g. by breaking hard lines with changes of mass and level, planting of hardy trees and shrubs, forming islands and so on. Essentially this would require study (partly in the hydraulic model) of economic ways of moving large masses of estuary bed material using the tides and river flows to best effect during or after construction of each stage. It should be noted anyway that an irregular regime would form naturally on the seaward side of the works. In this context, accretion between Hilbre Island and West Kirby - already a matter for concern if Hilbre is to remain a bird sanctuary - should also be studied on the model.

(b) Landscaping in relation to present and future industrial development (chapter 1.5 (x)) would merit special attention. Car parks associated with the scheme could be underground or, together with any present or planned caravan/camping sites, amply screened by trees.

## 2.4.8 Compatibility and planning

From the viewpoint of this chapter, preservation and diversity of amenities, scientific interest and fisheries (chapter 2.6), together with a wide variety of recreational facilities, can be compatible with road embankment crossings, water conservation and marginal reclamations for nature reserves or for agriculture (chapter 2.5). Since the amenity and other benefits of estuary works would enhance the attractions of both sides of the estuary, potential Green Belts could be preserved and housing in the Flintshire foothills may well seem more logical than in estuary lands at or below sea level (chapter 2.5). Thus the crux of compatibility may rest solely upon decisions as to the type and siting of industry (chapter 1.5).

## 2.4.9 Finance

Financing of some of the amenity and recreation provisions outlined above is a "distributional" aspect not covered in Phase I. Nevertheless it could create complex and important problems meriting attention in Phase II, especially since design of specific schemes must take account of the extent to which extra works for these purposes would be financed or would have to be self-supporting. Appendix E7 contains a discussion of some of the economic problems involved.

## 2.5 OTHER LAND USES

### 2.5.1 Areas, methods and types of reclamation

- (a) There are 31,500 acres in the Dee estuary bounded by the highest spring tide mark and a line joining the Point of Air to Hilbre Point. About 5,000 acres are high marsh which support vegetation, 6,000 acres have a veneer of mud, there are 15,000 acres of drying sandbanks, the remaining 5,500 acres being low water channels.
- (b) More than 200 years of progressive reclamation have produced 11,000 acres of land further upstream, 4,000 of which are now grade II agricultural land and 4,000 are used for housing and industry.
- (c) Enclosures of perhaps half of the present high marsh would produce (after reduction of salinity) land of similar agricultural quality. The remainder of the estuary would require increasing capital expenditure the lower the land and the nearer the mouth of the estuary (section 5.4.2).
- (d) Areas which do not at the moment support vegetation or are not covered by mud which would quickly grow grass, could be a liability when they dry out (section 5.4.3).
- (e) If positive measures were not taken for conversion to agricultural use or for industry or housing the sands would have to be covered by water. This can also be regarded as a long-term method of conversion to agricultural use, since small areas of shallow, even brackish, water will quickly grow weeds and cover the bed with rotting vegetation once the tidal scour is removed.
- (f) In many ways, however, it is better to let the sea do the silting if the reclamation is not required immediately since the process can be rapid in front of recent enclosures.
- (g) The highest marsh is above all but the highest spring tides but 85% of the estuary lies below the mean high water mark and 17% below mean sea level. All reclamation for agriculture, industry or housing would require drainage ditches (section 5.4.2). The water levels proposed in the existing canalized reach would preserve the gravity drainage of Sealand. The same would apply to new reclamation above a level of about +10 ft O.D. but lower areas would require pumping.
- (h) Foundations for large industrial structures might need expensive sand compaction or piling. Domestic building, however, would require

### 2.5.1 Areas, methods and types of reclamation (cont'd)

little more than normal strip footings and both would derive advantage from the large areas of level ground for laying out roads and services.

### 2.5.2 Land for industry

The traditional structure for industry, a source of raw materials, is absent in the estuary but suitable land with good communications to a major point and an industrial complex, plus ample water supplies, would prove an attraction if labour could also be found. Power supplies (gas and electricity) would be no more expensive than in alternative new industrial locations. The need for pumping and a long sea outfall could make waste disposal more expensive although, as the standards for trade effluents rise generally, this might not prove a serious deterrent. Visual and other amenity considerations (e.g. fumes) may be the greatest limitation on industrial development. There may be strong arguments for preventing the spread of tall industrial structures across the estuary flats without some over-all plan for grouping and relation to the surrounding hills. The need for large areas of water, however, could be considered an advantage in bounding and reflecting such developments.

### 2.5.3 Land for housing

(a) The estuary region might seem attractive for housing. Improved communications from a crossing scheme should put a large variety of jobs within range of the commuter and, if industry were also attracted to the area, there would be a demand for housing within a short radius.

(b) Placed between the conurbation of Merseyside and the National Parks of Wales in one direction and Chester and the sea in the other the estuary region would be attractive for leisure activities.

(c) Proposals have been made for a town on an artificial island in the estuary<sup>6</sup> where the charm of waterways and bridges could be exploited. There may be greater scope, however, for creating an attractive environment by confining development to the surrounding hills and using the estuary itself for other purposes.

### 2.5.4 Opencast coal mining

(a) The Opencast Executive of the National Coal Board are considering the exploitation of a seam in the estuary off Neston. Excavations to a depth of more than 200 ft might be needed over an area of perhaps 500 acres. De-watering would require an encircling bund in the absence of other estuary works. The whole area would not be excavated at once but, while the operation lasted, there would be a stock-pile of overburden.

#### 2.5.4 Opencast coal mining (cont'd)

Reinstatement could either be to the existing estuary flats or the bunds could be left and a lake formed inside them.

(b) If the seam is worked, it would probably take only a few years and could be staged with other proposed estuary works, possibly with some multi-purpose savings.

#### 2.5.5 Land ownership

(a) A drawing was prepared based on information supplied by the Dee and Clwyd River Authority, John Summers & Sons Ltd., the Crown Estate Commissioners, the Wirral and Hoylake Urban District Councils and the Mostyn Docks and Trading Co. Ltd.; copies were circulated to Flintshire County Council, the Nature Conservancy and the National Trust for comment.

(b) Apart from a small area at the Point of Air none of the land in the estuary below the highwater mark has been registered.

(c) Drawing 13 is intended to give only an indication of types of ownership and has no legal or other significance.

#### 2.5.6 Improvement to existing land

(a) The land in the flood plain of the Dee upstream of Chester is mainly Grade III agricultural land used for grazing. Two reports have been written <sup>102, 118</sup> on the scope for improvement of the drainage and the reduction of flood hazard. The recent report has been adopted by the Dee and Clwyd River Authority as the basis for works to be carried out in sections which can be justified economically as funds become available. None of the schemes seek to limit the extent of flooding in severe conditions but rather to limit the period in which flood waters remain on the land and to enable the ground water table to be controlled by pumping. It is expected that the reduction in the area of water-logged land will gradually raise the agricultural rating of the area as a whole.

(b) An estuary scheme cannot do anything to reduce the area of flooding in extreme conditions but, by providing a water level in the estuary close to the present low tide at Connah's Quay, the incidence of water-logging may be reduced (with sluices at one end of Chester weir - section 5.5.4) in those areas upstream of Chester for which existing proposals would otherwise prove uneconomic.

2.6.1 Salmon and sea trout \*

(a) The importance of the Dee as a salmon river is fully recognized and its value is enhanced by the early runs of fish compared with those, for example, in the Conway and Lune. The runs of sea trout, although far less important, are none the less significant.

(b) The approach, therefore, in developing the various multi-purpose <sup>6</sup> estuary schemes has been not only that this natural resource must not be destroyed <sup>+</sup> but that active measures should be incorporated to offset any harm caused by the estuary works and, preferably, to effect at least marginal improvements. At the same time, it was ensured that the associated engineering and other work would be both feasible and economic. They comprise the following, with the specific minimum aim of safeguarding the total numbers of fish and the feature of early runs :-

- (i) directing a research programme as outlined in appendix F2 and implementing the relevant findings as necessary;
- (ii) designing schemes to retain estuary shapes and conditions attractive to fish;
- (iii) providing suitable fresh water discharges <sup>76 pp. 11 et seq.</sup> and fish passes to attract the fish and enable them to ascend the river easily; providing facilities for smolts and kelts to migrate to the sea with least hindrance;

\* The views expressed in this section and in appendix F2 were discussed originally with the late Mr. F. T. K. Pentelow. They have since been amplified in the light of full discussion with the Ministry of Agriculture, Fisheries and Food, the Fisheries officer of the Dee and Clwyd River Authority and Dr. J. W. Jones of Liverpool University. Since the first two authorities are members of the Technical Working Party, it is appropriate in this report to state only that Dr. Jones is in complete agreement with the views expressed.

<sup>6</sup> Salmon & sea trout interests would not be affected by any single-purpose, pure bridge crossing schemes, since the river discharges into the estuary would be unchanged.

<sup>+</sup> No account is taken in this report of the possible effects of the recent outbreak of columnaris-type salmonid disease in certain rivers of N.W. England and Scotland, on the assumption that an outbreak in the Dee would not destroy the fishery, would have only short-term effect and would not excuse a less positive policy than is outlined.

2.6.1 Salmon and sea trout (cont'd)

- (iv) taking steps to reduce losses by predation;
- (v) largely or wholly replacing netting in the estuary by controlled trapping at fish passes. While some fish could be sold commercially by the operating authority, more than enough could be allowed to ascend to preclude the need for compensation to sporting interests upstream. Traps would be so designed that those fish being allowed to ascend would receive minimum disturbance (e.g. by manhandling). Since the estuary works would displace the tidal netting in the present canalized reach of the Dee estuary below Chester weir, the opportunity arises to preclude netting in any newly created "head of the estuary" downstream of the works; indeed, the proposed schemes could well be regarded as pointing the exception to a "Bledisloe" report <sup>81</sup> policy, in creating the conditions envisaged rather in the "Hunter" report <sup>78</sup> and enabling enlightened fishery management techniques to be introduced;
- (vi) using modern fishery instrumentation <sup>82</sup>.
- (vii) encouraging water authorities to abstract where practicable from estuary reservoirs or river rather than from upstream of Chester weir, thereby increasing river flows right down to estuary pumping stations and, where required, providing retention storage;
- (viii) diverting the worst trade wastes from the river by separate sewer;
- (ix) encouraging/enforcing measures to reduce pollution from sewage and trade effluents. Items (vii), (viii) and (ix) would more than offset the present danger of slugs of polluted water forming a fish barrier in the canalized reach during low river flows.

(c) Schemes designed to maintain an estuary shape downstream of the works would have the attraction of trapping considerable fresh water in the estuary, with only slow dispersal to the sea. Outer line barrage schemes, not having this estuary feature, would reduce the Dee to the status of a small river and the fishery would suffer accordingly; moreover the cost of maintaining suitable approach channels to fish passes, known to be difficult for fish to locate in a long featureless bank, could be prohibitive.

## 2.6.1 Salmon and sea trout (cont'd)

(d) Again, true barrage schemes retaining large fresh water lakes may not prove ideal for salmonid fisheries. The effects of delays in descent of emolts and kelts seeking the outward route to the sea together with pike and perch predation<sup>79</sup>, are arguable. Much depends upon the amount of water flowing through the lake and upon its depth. In Llyn Tegid (Bala Lake) for example, smolts are known to move along the shallows away from the pike and perch. Sea trout, given the right conditions, would leave an estuary lake but, if they remained, they would form a valuable fishery only if predators could be destroyed continuously, which is considered unlikely in this instance; in fact, it would be preferable to accept a coarse fishery which, although meeting a big demand, would not have such high money value. A final but important aspect is that steady discharges to attract fish would be much augmented by flood spills; in a true barrage scheme, these would be large but rare in a fairly dry series of years because they would occur only after the reservoir had filled. For estuary pumped storage schemes as proposed, however, they would be smaller but relatively more regular because they would occur, even over the dry years, whenever the river flow exceeded the capacity of the pumps (rated finally, say, at little more than the long-term average daily flow) and this latter situation is much more favourable for salmon and sea trout. In either barrage or pumped storage estuary schemes, of course, special flushes of water could be released in dry periods to induce any large numbers of fish congregating downstream to ascend into the lake or river respectively. Incidentally it is not certain whether, for the Dee as in some other rivers, the effect of spates on salmon movements is more marked in the upper (low-flow) reaches than in the estuary.

(e) It is envisaged that abstractions from Dee estuary reservoirs could grow at 10 mgd/year to 300 mgd (or pro rata less for smaller schemes) over 30 years, although it is unlikely that as much as 250 mgd of this would be exported from the river basin. Even if it were all exported there would remain of the available long-term average river flow some 100,000 mg discharged to the sea during floods, albeit mostly between October and April inclusive, plus a special allocation of 70 mgd as a guaranteed minimum release at all times including drought years. Thus the pattern of river flows would change only gradually over several decades which should be ample time for the fishery to become adapted and even improved by research and management. Nevertheless it is recognized that the introduction of sluices and fish passes are radical changes which will be there as soon as a scheme starts.

(f) Dee fish move in all months of the year<sup>80 pp. 88-90</sup> but have seasonal peak runs. Thus allowance has been made for maintaining flow at all times to avoid prejudicing this activity. Moreover, complete discharge continuity would be maintained by pumping through fish passes during the high stage of the tidal cycle.

## 2.6.1 Salmon and sea trout (cont'd)

(g) Although a Borland type of fish pass <sup>75</sup> would be the cheapest, a more expensive modified "pool" type suitable for low heads at the barrages and with more flexibility in design both to incorporate flood discharges and to attract fish to run early, is allowed for in the estimates pending research results. Early in the season (hence in cold conditions), fish are usually in better condition but have less urge to ascend the river than in the summer and passes need to be easy to surmount. Thus there would be unusually long passes comprising a series of gradually rising pools, with low-velocity weirs (less than 5 ft/sec.) connecting them. The rise between pools could be as little as 9 inches initially but, once early fish had started the ascent, they would probably accept rises of 12 to 15 inches easily enough. There would be long, deep and sheltered holding pools at the top, whence fish would ascend the river as the top sluices opened on the ebb tide. These provisions are designed to avoid fish drifting back on the ebb tide (in a zone attractive to predators) and delay or lack of fresh water causing them to lose the urge to ascend. Flood spills would be in the form of cascades over and, as needful, alongside the fish passes and routes with water speeds not exceeding 8 ft/sec. would be made to attract fish during epills.

(h) Spills or flushes could also be used to get the emolts out. When migrating, a shoal of smolts will follow a leader in passing through a grid. For example, smolts reared naturally in a mountain tarn at Dyrnogydd have been moved by raising the lake level, then "pulling out the plug".

(j) Predation of emolts, which migrate between March and May, by e.g. pollack, saithe (coal fish) and coastal birds, might be reduced if their release to the sea were controlled at the top of the tidal cycle. If they had also been acclimatized for, say, 10 hours <sup>80</sup> pp. 38, 39 in a brackish holding pond, their migration to the open sea need not be delayed.

(k) The extent to which fisheries might diminish until fish had time to adapt to the new conditions is unknown. It is emphasized, however, that because no-one can answer these questions definitely, it is assumed in this report that the estuary works would reduce the numbers of fish migrating during the season and alter the timing of the runs adversely, temporarily or permanently, unless the positive counter-measures described were taken. The economic justification for this approach is as follows :-

- (i) although fish ascend other than their home rivers, this is rare and hence Dee fish lost or gained are not respectively gains in, or losses from, other rivers. In particular, an increase in runs of Dee fish can be induced only by improving the Dee as a salmon producing river;

#### 2.6.1 Salmon and sea trout (cont'd)

- (ii) estuary commercial netting is known to be an inefficient means of obtaining salmon and controlled trapping at fish passes would be an economic use of manpower;
- (iii) on the basis of this, it has been considered prudent to include a provisional cost of £½ million for measures designed to protect the fishery. This may be an over-estimate, particularly since the fishery could well be marginally improved but no benefit is included for this.

(i) Various methods have been used to value the present total fishery and to differentiate between commercial (netting) and sporting interests. Ranges of total value (£1 to 2 million) were obtained - taking account of difference values between salmon and solely trout fisheries - but, in the event, the figures are not needed for Phase I purposes. This is in view of the schemes developed and because the proposed preservation policy is justified by the valuation and reinforced by not having valued other potential losses (amenity, hotel and trade interests associated with fishing) except for the element of amenity reflected in the value of private fishing rights. Some of the data used are reproduced for interest in appendix F3 (license receipts, numbers of fish reported caught, mileage of salmon and trout fisheries).

(m) It is recommended that the views of the Salmon and Trout Association and of interested local associations and bodies be sought in Phase II of the study.

#### 2.6.2 Sea fish

(a) The Lancashire and Western Sea Fisheries Joint Committee (L. & W.S.F.J.C.) have direct control of sea fishery interests in all estuaries and along the coast from the Teifi in Cardiganshire to the Duddon in Cumberland, with the sole exception of the Dee estuary for which the Dee and Clwyd River Authority are also the estuary fishery authority. Nevertheless, in practice and by arrangement with the River Authority, the L. & W.S.F.J.C. do perform many of the fishery functions in the estuary.

(b) A broad indication of the sea fisheries is given on drawing 13 and more data are given in appendix F4.

(c) The fisheries would be virtually unaffected by any pure bridge crossing scheme. Any outer zone barrage would almost certainly destroy the whols of the estuarial shrimp fishery, probably the flounder catch and something like half the cockle beds. The cockles might

### 2.6.2 Sea fish (cont'd)

re-set outside a barrage but this would depend upon the nature of the sand and the stability of the banks in the subsequent siltation. The shrimps would be unlikely to move outside where, in any case, the vessels now used by the shrimp fishermen would not suffice. A middle zone barrage, with a channel on the Welsh side and perhaps slow siltation on the Cheshire side, might not affect the fishery but would require the moorings to be shifted from Caldy to somewhere on the Welsh side.

(d) A major concern of the L. & W. S. F. J. C. is with potential dangers to the nursery zones for sea fish outside the estuary, a few miles from the shore; these could be damaged by the effects of local build-ups of nutrient salts (phosphates and nitrates) leading to high algal blooms. From this viewpoint, primary sewage treatment and sea outfalls much shorter than 3 miles are preferred to the sewage outfall proposed for e.g. Hoylake and N. Wirral. Also in this context, organic depositions from the R. Mersey are being studied at Liverpool University.

(e) It is concluded that the sea fisheries would barely be affected by the schemes proposed, since a significant estuary would remain in the multi-purpose schemes. The main problem to overcome would be to ensure that the Flintshire trade wastes diverted past the estuary works were diffused efficiently into the body of the tidal flow. In view of the distance, negligible fall and need to discharge against the tide, effluents which could not reasonably be treated before discharge or for re-use would have to be collected and pumped through a pipeline. If the flow were discharged in concentrated form through a long sea outfall beyond Point of Air, the nursery zones might be affected. Outfalls, in fact, should comply at least cost compatible with local by-laws and be quite close to the estuary works, either into a stable "ebb" channel (not the main flood channel chiefly used for migratory fish) or into a sand bank area giving wide dispersion through a natural sand filter. This matter could best be resolved only after suitable tests had been carried out on the hydraulic model. Fish could be tainted if not actually killed by some discharge and, in any case, early dilution of any cyanides and possibly of sulphides, each to the order of 1 ppm, would be desirable. See also appendix D3.

### 2.6.3 Trout and coarse fish

Appendix F2 refers to the coarse fishery in the Dee from Chester to south of Holt and appendix F3 mentions some 75 miles of salmon fisheries upstream in the main river and tributaries. As in the upper Severn and tributaries, the coarse fish (especially dace and roach) persist well into the salmon and trout reaches. In

multi-purpose estuary schemes, the present tidal reach below Chester weir would be converted to a slow-moving freshwater river from Chester, down the canalized section and through the upper estuary to the new sluices and migratory fish passes; this part of the river would undoubtedly become a coarse fishery but, especially during low river flows, its level could be well drawn down by pumping and predators such as pike could be kept under control if desired. There would be vast scope within the estuary works themselves for the creation of various valuable fisheries in the reservoirs and meres; new meres and ponds could be formed cheaply by dredging the mud and sand in nature reserves and other reclamations not needed for other purposes - or not needed for many years. In these ways badly needed recreational fisheries could be provided and fish farming for food need not be precluded. In Phase I studies, no specific costs and values are attributed to these fisheries which should be considered in detail later, when layouts and designs become firmer. A favourable ecological balance in lakes and meres would be obtained only with the help of suitable fish populations to control explosive growths of, for example, midges. Biological control is referred to in more detail in appendix D3.

## PART 3 - SCHEME APPRAISALS

### 3.1 INTRODUCTION

#### 3.1.1 Dominant factors

(a) The benefits that could derive from works in the estuary are many and varied. The costs of achieving the benefits from a road crossing and from water conservation dominate the choice of schemes. In general one or two thousand acres of land reclamation could be provided at small extra cost if either a crossing scheme or a water scheme or both were required.

(b) By comparison with the benefits from traffic and water conservation, the valuation used for land reclaimed (which could be used for amenity, recreation, agriculture, housing or industry) shows a small benefit and if the whole estuary were reclaimed it would amount to only a tenth of the benefits to traffic from a crossing.

(c) All the benefits and costs given in part 3 are present values (appendix E3).

#### 3.1.2 Estuarial regime

(a) As described in section 2.2.5, the estuary has been steadily silting up for some centuries and this process is continuing. Reclamation works have led to a loss of tidal cubature which has accelerated the process. Observations in this and other estuaries have shown that the construction of works interfering with tidal flow, while sometimes leading to local deepening and stabilizing of channels, is nearly always followed by accretion of adjacent areas.

(b) The hydraulic model tests of the estuary which are planned to start shortly should yield valuable information on this subject.

(c) The illustrated schemes for embanked works in the estuary have been arranged to form a residual estuary of tapered shape leading from the river outlet. This could help to maintain the tidal ebb and flow needed to form a deep channel with resulting advantage to flood prevention, navigation and migratory fish. The hydraulic model could be used to verify or modify the shapes chosen which are only typical and provisional at this stage.

### 3.1.3 Scheme purposes

(a) It follows from the last section that, apart from the construction of a series of bridge spans from shore to shore (which would not affect tidal flow), all schemes examined would be multi-effect and by inference multi-purpose, even if each were conceived for a single purpose. Thus any scheme for embankments in the estuary would require multi-purpose planning.

(b) It may be thought, however, that either of the viably dominant purposes, i.e. road crossings and water supplies, could be excluded if found desirable. The implications of these exclusions are referred to in chapter 3.3 under the heading 'separated purposes' solely as an aid to the economic appraisal and it is not proposed that such schemes should be constructed. Nevertheless, since multi-purpose schemes described in chapter 3.4 are based on similar road alignments and reservoir layouts, aspects of each purpose have been described separately and in some detail in chapter 3.3.

### 3.1.4 Road alignments

In the outline descriptions of schemes which follow, certain patterns of road alignments recur. These typical alignments are shown on drawings 2 to 4 where they are associated with multi-purpose schemes. They are referred to in part 3 as road alignments X, XX, Y and ZZ for convenience.

## 3.2 BRIDGE CROSSINGS ONLY

### General

(a) A bridge scheme, if carried out, would have virtually no effect on the present estuary regime and changes now taking place (e.g. the growth of the marsh off Parkgate) would be unaffected. However, it would not preclude the independent development of the estuary for other benefits.

### Outer zone

(b) A crossing could be made in the outer zone on a continuous series of bridge spans totalling five miles. The traffic model predictions for 1981 show that dual two-lanes would be required by that date and by inference from the predictions for other crossings they would suffice until the end of the century. The present value of the cost of a bridge, its approaches and the running costs would be about £35m. This exceeds the expected traffic benefits to the end of the century which have a present value of £28m (rounded to £30m in 1.4(b) (vi))

### 3.2 BRIDGE CROSSINGS ONLY (cont'd)

#### Middle zone

(c) The margin of expected benefits (£45m) over the estimated costs (£40m) is small for a crossing in the middle zone on a continuous series of bridge spans (scheme W).

#### Inner zone

(d) The predicted congestion in the Queensferry/Connah's Quay area could be relieved by a single crossing in the inner zone (alignment APB on drawing 1). For a cost of £9m the benefits to traffic would be £12m. These figures would apply only if no other estuary crossings were made before the end of the century.

(e) The length of bridge required would be quite small because long approach embankments could be constructed near the Broken Bank with no significant effect on tidal movements. This type of inner zone crossing alone has not therefore been listed in chapter 3.4 as a multi-purpose scheme.

### 3.3 SEPARATED PURPOSES

#### 3.3.1 Embankment crossings without water conservation

##### General

(a) Considerable savings in costs of crossings could be made by building road embankments in the estuary to reduce the length of bridge needed. If long embankments were built with only a short bridge over the ebb channel, deep scour holes would form around the piers and at the ends of the embankments as predicted by Matheson<sup>112</sup>. Large extra construction costs, however, due to scour could be tolerated for a reduction in bridgeworks. Model tests and further site investigation could be used to achieve an optimum proportion of embankment to bridge length if such an arrangement were acceptable on other grounds.

##### Outer zone

(b) A scheme primarily for a road crossing in the outer zone has not been pursued since the cost of an embankment would be comparable with the benefits and there are other adverse factors (chapter 3.5).

Middle/inner zone

(c) No road crossing on an embankment could be considered for the middle zone without specific provision being made for the siltation that would occur upstream and downstream. The shifting channels, in which the extended ebb tide and river flow scour away the silt and sand brought in on the flood wave, would be seriously affected. This would have an immediate effect upon the navigation to Connah's Quay and, as the siltation progressed further, upon the port of Mostyn. There would also be an impact on the amenity of the estuary. Nevertheless, if an embankment from Neston to Thurston cliffs enclosing a mere with a water level maintained above that of the highest spring tides were acceptable for preserving amenity and if the uncontrolled extension of the marshes to seaward were tolerable, the cheapest combination of embankment and bridge could be used for a crossing.

(d) Pending the results of tests, a bridge 4,000 ft long has been allowed in estimating the cost of a crossing on alignment X at £23m and the formation of an amenity mere at a further £1m.

(e) Some navigation to Connah's Quay might be maintained by the construction of half-tide training banks upstream of the crossing. Their cost would be about £1m but they would still further accelerate accretion each side of the channel.

(f) However apart from the loss or change of scientific interest that the growth of the marshes would bring, the subsequent development of the estuary for recreation, agriculture, housing or industry would not be prejudiced. The whole area upstream of the crossing, except for an extension to the canalized reach could be reclaimed by heightening the training banks to above the level of the highest tides. The cost would be about £5m as two closures would be involved. Where agricultural use was planned, it would be advisable to wait some years before heightening the banks until some silt had been deposited over sandy areas.

(g) An inner zone crossing, from Shotwick to Flint, could be added at a cost of £3m to road alignment X to form alignment XX and increase the benefits to £51m. The cross-Dee traffic flows do not show that a link is needed from Flint to Greenfield but it may be desirable for other traffic. (Phase II studies would help to determine whether the investment would be viable).

### 3.3.1 Embankment crossings without water conservation (cont'd)

(h) A combined middle and inner zone crossing on road alignment Y would give benefits of £41m for a cost of £19m. The embankments would lead from the shore at Neston and Burton Point to an interchange in the estuary. Further embankments would carry the road across the estuary to Flint with a short bridge over the ebb channel. Another interchange at Flint would distribute the traffic to Connah's Quay area, towards Mold and along a new coastal road past Greenfield and up to the B. 5332 as in a middle zone crossing.

(j) The effect of a combined crossing on accretion in the estuary would be smaller than for alignment X as the embankments would be about three miles further up the estuary and, instead of cutting across the drainage pattern, they would run parallel to it for much of their length. An area of high marsh would be enclosed off Denhall. The existing training walls at half-tide level would be extended to the bridge and siltation could be expected off Flint. Navigation would not be affected to the same extent as with alignment X. Although the benefits would be reduced by the more devious route from the Wirral to North Wales, the construction costs would be lower due to the more sheltered position of the crossing and a mere off the Wirral shore for amenity reasons might not be needed.

(k) Traffic studies in Phase II may show that there are large extra benefits from traffic between the Shotton, Hawarden, Connah's Quay area and Liverpool and a variant of scheme Y (scheme YV) would be to provide a link direct from the interchange off Neston to the coast road at Oakenholt. A further area outside the Broken Bank would be reclaimed by the embankment for this link.

(l) Benefits of £45m and costs of £25m are representative of the foregoing for the purposes of item (4) in the table in paragraph 1.4(b)(vi).

### 3.3.2 Water supplies

#### General

(a) A scheme for water conservation in the estuary could be pursued even if no road crossing were required. It would give amenity and recreational benefits and could provide reclaimed land for agriculture, housing, industry and opencast coal mining. This is discussed only as an aid to economic appraisal and is not proposed as a scheme, however, because crossings are clearly needed and would certainly be provided over the reservoir bunds and using bridge connections or, with an outer zone barrage, over reclaimed land in the middle and inner zones.

### 3.3.2 Water supplies (cont'd)

(b) The gradual increase in the demand for water supplies from the potential of 300 mgd with Dee estuary storage is discussed in appendix D2, where it is assumed for present purposes that full use of the resource might not be made for between 30 and 60 years. An analysis of the costs of providing storage by direct impounding or by pumping into bunded reservoirs has shown that, for the case of the Dee estuary flats, the extra expenditure on labour, plant and materials for constructing a scheme in stages is more than offset by the reduction in present value of the work. Even if the discount rate were 5% and full development were required in 20 years the present value would be less for staged construction than for a scheme to provide the full storage immediately. There is the further and unmeasured advantage of being able to stop building more stages if the demand for water supplies were to level off or if cheaper alternatives became available.

#### Outer zone

(c) As outlined in section 2.3.3 a barrage could be built at the mouth of the estuary to impound sufficient water for development of the water resource. Nevertheless it would be difficult to develop the scheme in stages and, in the context of this section, it could not provide the cheapest separated-purpose scheme.

#### Middle/inner zone

(d) A scheme for using pumped storage reservoirs is outlined in chapter 2.3 and appendix D3. Its chief effect would be upon navigation since a tidal barrier would be required downstream of Connah's Quay. The first stage would be at least two bunded reservoirs and a flood balancing basin. Further reservoirs could be added as the demand for water rose and staged development of abstraction, treatment and delivery works could be easily arranged.

(e) The cost of diverting the existing grossly polluted trade effluents and of providing for their future increase is controlled by the distance downstream of the tidal barrier. With the barrier at Flint the cost would be £1m increasing to £4m with the barrier at Greenfield.

(f) The benefits of water supplies estimated in appendix E5 can be taken as £40m for 60 years development and £70m for 30 years development. The costs of water conservation in the two cases would be £13m and £20m with the addition of £17m and £35m respectively for the costs of treatment and transmission.

### 3.4 MULTI-PURPOSE SCHEMES

#### General

(a) The whole of the benefits of water conservation and of a crossing could be derived, without significant reduction of the remaining benefits accruing to the separated purposes, by constructing a multi-purpose scheme.

#### Outer zone

(b) Enclosure of the whole estuary would give great freedom in the choice of road alignments. Obstruction to cross-Dee traffic would be reduced leaving a canalized river, easily bridged and similar to that now existing above Connah's Quay. The closure embankment could carry a railway if this were viable while, in order to avoid congestion in the north of the Wirral, the roads could be kept to the middle and inner zones.

(c) The areas below mean sea level in the lower part of the estuary would be the most expensive to reclaim for agriculture, industry or housing and should be flooded for water conservation. The volume stored below mean sea level could not all be used due to the danger of salt water seepage when the reservoir was drawn down. The top water level of a lake fed directly by the river could not be higher than + 10 ft O.D. to avoid the possibility of flooding the Sealand area (chapter 2.3). Movable-bed hydraulic model tests of Liverpool Bay would be needed to show whether there would be unfavourable effects on the approaches to the port of Liverpool and whether a low water channel of enough capacity could be maintained up to the sluices in the barrage, to discharge a large flood after a long dry spell.

(d) Estimates have been made for a closure broadly on the line Point of Air to Hilbre Point but a short estuary has been included with sluices at Mostyn, where advantage could be taken of the construction method to form a locked basin as an extension of the port facilities, if it were shown that a navigable channel could be maintained.

(e) Some aspects of water conservation would probably justify the formation of an enclosing bund at about the 0 ft O.D. contour behind the barrage and the canalization of the river along the Flintshire shore as far as the sluices. In this way a reservoir could be formed to have a useful storage of 50,000 mg between the levels of datum and + 20 ft O.D., water being pumped into it from the river. Better use would be made of the main barrage embankment which would need a crest level of + 33 ft O.D. as protection against wave attack from the sea. By separating the river from the reservoir, advantages to water quality and fisheries would be obtained. Some of the advantages of pumped storage listed in chapter 2.3 would also accrue but sub-division of the

reservoir as recommended for water quality in 2.3.5 would be expensive due to the deeper water; difficulties with thermal stratification would be accentuated.

(f) Salinity problems would be insignificant due to the outward seepage of some 30 mgd of which, say, 10 mgd would be lost to the sea while the remaining 20 mgd would drain to the river again and be re-pumped.

(g) Amenity meres along the Cheshire and Flintshire shores would not form a part of the proposals for water conservation and, if required, would be a separate cost to the scheme. The large area of reclamation made available would either have to be stabilized with vegetation or covered with water. The potential for recreation, housing or industry would be large.

(h) The scheme would be very costly and would not lend itself to staged construction. The present value of the costs (paragraph (p) below) would be 40% higher than for a multi-purpose development further up the estuary but the benefits would be slightly more. The benefits from water supplies would be unchanged. Traffic benefits would be those for a middle and an inner zone crossing and, unless a much higher valuation of reclamation could be justified than one based upon agricultural prices (appendix E6), benefits from land would be insignificant in relation to the costs.

#### Middle/inner zones

(j) The road alignments outlined in paragraphs 3.3.1 (d) to (k) could be combined with the pumped storage reservoirs described in paragraph 3.3.2 (d) to give multi-purpose schemes. Examples are illustrated in drawings 2, 3 and 4.

(k) The embankments needed for road crossings would form part of the bunds enclosing the reservoirs but would have to be higher than required for a road alone.

(l) Scheme X is close to being the sum of the separated purpose layouts for road and reservoirs. If a middle zone crossing were built and it was then decided to go ahead with a water scheme it would be only at a later stage of construction, say between 15 and 30 years after the start, that alterations would have to be made to the crossing. The present value of these could be less than for building the crossing to the required level initially.

### 3.4 MULTI-PURPOSE SCHEMES (cont'd)

(m) The XX and Y schemes would show a greater saving if the two main purposes were planned at the outset, since the alterations required for the road embankments and the substitution of sluices for a bridge would have to be made as a preliminary to modifying a separated-purpose crossing layout for a multi-purpose scheme.

(n) The Z schemes differ from the X schemes in having the sluices in the embankment of the middle zone. These would not be built unless a multi-purpose project was chosen at the beginning.

(o) The layout of a multi-purpose scheme would be strongly influenced by the results of model tests to discover the optimum shape for the estuary (section 3.1.2). Amenity and land-use requirements would also influence the choice of layout. Schemes Z or ZZ, however, would not be appropriate unless water conservation were a purpose from the start. Some possible layouts are discussed in chapter 3.6.

(p) Outer zone multi-purpose schemes would have benefits of about £120m for costs of £105m or, with 60 years development of water supplies, £90m and £85m respectively. Middle/inner zone multi-purpose schemes would have benefits of £115m for costs of £75m or, with 60 years development of water supplies, £85m and £50m respectively. These are characteristic figures and certain ranges are given in appendix E9. The characteristic figures should be used in order to ensure compatibility in the economic comparisons. Any small differences shown by present estimates could easily be reversed after a re-assessment following a more detailed traffic study, a study of the cumulative effects of smaller benefits and the completion of some hydraulic model tests to clarify some engineering aspects and hence costs.

### 3.5 ASSESSMENT

#### 3.5.1 Outer zone schemes

(a) Outer zone multi-purpose schemes are recommended for outright rejection in Phase I for the following reasons:-

- (i) high costs in relation to benefits; higher investment risk;
- (ii) siltation of coastline outside barrage; potential harm to adjacent coastline e.g. Liverpool;
- (iii) probable immediate loss of Mostyn as a port;
- (iv) adverse effects on salmon runs (section 2.6.1);

### 3.5.1 Outer zone schemes (cont'd)

- (v) most harmful to sea fisheries (section 2.6.2);
- (vi) virtual loss of present bird interest;
- (vii) large reservoir less flexible for controlling algal troubles;
- (viii) total estuary loss ("wilderness" and Hilbre amenities);
- (ix) less (or more costly and uncertain) Wirral amenity.

(b) The possible set-offs to these disadvantages could not influence the rejection. They are that: (1) the outer zone might be best for a commuter/holiday rail connection (2) the most land would be reclaimed and (3) different bird interests would arise.

(c) Outer zone bridge schemes are not viable. Outer zone crossings mainly on embankments are also recommended for outright rejection in Phase I because of items (i), (ii), (ix) in (a) above, least favoured road location and lowest returns from traffic.

### 3.5.2 Middle/inner zone schemes

Staged multi-purpose schemes are recommended after studying 'separated-purpose schemes' and scheme W as described in chapter 1.4. An inner zone crossing alone should be considered only if it is decided to carry out no works in the estuary.

## 3.6 MULTI-PURPOSE SCHEME VARIANTS

(a) With crossings in the middle and inner zones a choice of tidal sluice position in either embankment arises and this has an effect on the shape of the residual estuary downstream. As mentioned in chapter 3.1.2 model tests are expected to provide guidance on the best shape.

(b) Model tests would also show whether the position of the estuary along either shore or in the middle would be preferred for hydraulic reasons. The choice is however expected to be wider than in the case of the length of estuary.

(b) The three road networks (middle zone, middle zone plus inner zone and combined middle and inner zone), the two lengths of estuary (long and short) and the three positions of the estuary (left, middle, right) give 15 variants. Nine are illustrated separately X(L, M, R)

3.6 MULTI-PURPOSE SCHEME VARIANTS (cont'd)

XX (L, M, R) and Y (L, M, R) and six are illustrated in three plans Z (Z) (L, M, R) on drawing 5.

(c) An estuary on the left (schemes XL, XXL, YL, ZL and ZZL) gives the least area of land reclamation on the Welsh side but may be the most advantageous for the port of Mostyn. Water for amenity along the Wirral shore could be provided by a mere.

(d) At the opposite extreme, an estuary on the right would give a deep tidal channel along the Wirral shore and the greatest scope for amenity or land reclamation on the Flintshire side. Intermediate positions of the estuary would give a range of areas of land reclamation and amenity characteristics.

(e) In all the schemes the benefits from water conservation would be identical and the benefits from the three types of road crossing would be unaltered.

(f) Although details of road alignments, embankment elevations, water levels, areas of reclamation and amenity provision are given for three typical schemes on drawings 2, 3 and 4, they should not be regarded as firm but as an indication of the proportions of a multi-purpose scheme such as could be built for the capital sums used in the economic analysis.

(g) The choice of an optimum scheme would follow a process of elimination as outlined in paragraph 1.3.7 (g).

4.1 Introduction

(a) The terms of reference require that an assessment be provided of the potential benefits and costs to the community of a Dee estuary bridge with or without an embankment crossing. The task is complex because of the wide variety of the benefits and costs involved. The study embraces traffic, land reclamation, water resources and "intangibles" such as amenity, as well as requiring reference to the possibilities of urban redevelopment and industrial growth.

(b) Particular valuation procedures are set out in detail in appendices E3 to E9.

(c) The purpose of part 4 is to explain the general approach to the evaluation of benefits and costs, with only incidental reference to particular procedures for purposes of illustration. As a glance at the references (appendix B5) will show, there are many economic studies of one or another of the problems concerned; but the methodology of such studies stands in need of further development by economists and, in any case, it must always leave some issues to be resolved by the policy-maker. Further, there is little satisfactory material concerned with the practical problems of evaluating multi-purpose schemes, so that the present study is in some degree novel and has called for much discussion of concepts and search for understanding among the different specialists concerned.

4.2 The nature of benefit-cost analysis

(a) Investment decisions commit scarce resources to particular uses through time and it is important for the economic welfare of the community that such decisions be taken efficiently. In the private sector, the decisions are taken by individuals concerned with profitability and governments enter the picture only indirectly. The government itself, however, is also a considerable direct user of investment resources and some technique is required to choose between alternative possible public investments. In some respects, the procedures used can parallel those that might be used in the private sector (such as the discounted cash flow technique) but there are also a number of difficulties peculiar to the public sector. Benefit-cost analysis is the technique that has been evolved to deal with these.

(b) The analysis proceeds by defining the relevant projects (alternative possibilities within the frame of reference provided). The cost of these (value of the necessary capital and operating resources) is then ascertained. Next, the benefits flowing from the investments must be

#### 4.2 The nature of benefit-cost analysis (cont'd)

identified and appropriately evaluated. In the case of both benefits and costs, the procedure adopted should attempt to distinguish real benefits or costs from transfers (gains compensated by losses to others), and benefits deriving from the investment from other benefits that would arise through time in any event. Finally, real benefits and costs must be related in a fashion that aids policy selection.

(c) The procedure is easier to describe than to use. Subsequent sections will indicate some of the important difficulties met with in this study and the methods adopted to deal with them.

#### 4.3 Some conceptual problems

(a) A private individual making an investment decision will do so in the light of its expected profitability. If a government believes this criterion to be unsatisfactory in particular instances (because it ignores considerations believed to be of concern to the community), there is a variety of weapons available that can be used to modify such decisions (subsidies, regulations, prohibition and so on). When the investment is to be made by the government itself, however, the indirect benefits and costs must be included as far as possible in the project appraisal. At the same time, it is important that the appraisal be kept simple and that the results be presented in a form that facilitates comparison with other projects. These two requirements are always likely to conflict.

(b) In the case of the present study, a Dee estuary crossing might result in economic growth in North Wales. This would be an important indirect benefit but to attempt to evaluate it, would have gone beyond the limitations imposed by the terms of reference and in any case would have created tremendous problems of comparability with other studies. The fact that these possible consequences have been left aside, however, needs to be borne in mind when interpreting the conclusions of the study (see below and appendix E6).

(c) Again, the nature of the benefits concerned is by no means simple. Some (such as reductions in road congestion or the increased availability of water) have value-characteristics not fundamentally different from those of goods bought and sold in markets. Others (such as the provision of water on a shoreline) are much more difficult to value meaningfully in money terms. Benefits of this latter type have been enumerated but not evaluated. (As a guide to policy decision, however, it has been possible to estimate the cost of providing a mere off the Cheshire shore immediately rather than in thirty years time; this can be treated as one kind of "cost of amenity").

#### 4.3 Some conceptual problems (cont'd)

(d) Another aspect of this problem relates to the fact that the context within which the "benefits" of the project are to be assessed is not unambiguous: the concept of "community benefit" is less easy to interpret than the notion of profitability. Which "community" is concerned? The work was commissioned by the Ministry of Land and Natural Resources, an organ of the central Government. It results from the activities of a Working Party on which are represented a great diversity of sub-interests: regional bodies and local governments, water interests, housing interests and so on. Nor are all the interests that might be affected by an estuary scheme directly represented, e.g. industrialists.

(e) Manifestly, not all the groups concerned have the same interests and what is regarded as a benefit by one sub-group might be obtained at the price of imposing a cost upon another.

(f) It has been necessary and, indeed, useful to limit the Phase I study to discovering whether a crossing could confer worth-while benefits for the community of Great Britain as a whole, leaving aside the question of the incidence of benefits and costs among particular sub-groups. Lying behind this procedure is the presumption, reasonable but not necessarily completely valid, that if the benefits are worth having, means of finance might be found that achieved reasonable equity among the groups affected without major detriment to the generation of the benefits themselves.

(g) Certainly, further study of the implications of a scheme for particular groups and interests could well be considered in due course.

#### 4.4 The data

(a) A scheme completed in 1976 would provide benefits and impose operating costs running into the next century. The benefits and costs thus need to be related to the size and distribution of population during that period. Population predictions are given and their application to the study explained in appendix E1. It is important that the margins of error involved in this type of prediction be recognized. An illustration is provided by the fact that projections being made after the end of the second World War indicated a declining population by the present day and a total population of no more than 20 - 25 million at the end of the century. Present projections put the end-of-century figure at more than 70 million. This (perhaps extreme) example suggests that, had it been feasible, it would have been useful to test a range of population assumptions. In fact, it has been possible to obtain some indication of the importance of population growth for traffic benefits. In the case of water, the recommended schemes are staged, which reduces the importance of errors in prediction (see below).

(b) A quantitative estimation of benefits through time faces special problems in the case of public investments, in that the "products" to be valued are not normally bought and sold, or are bought and sold at prices that do not reflect supply and demand conditions in the market in question. This is true of both the major benefits (roads and water) which are quantified. In neither case is there a market price that acts as a general rationing device in the economist's sense. Indirect measures of benefit must therefore be found, and these must take account of the fact that one reason for the lack of a market may be the belief that market prices would not reflect the true opportunity-costs of using resources for this rather than other purposes, because availability of the product confers community benefits over and above those enjoyed by individuals. (Clean water, for example, may be thought to have a value greater than consumers buying in a free market would place upon it, because of its contribution to public health.) The estimation of traffic benefits follows broadly the procedure of earlier studies. Water has been evaluated by reference to the opportunity costs of alternative sources of supply. The unavoidable difference of procedure, which is one of the special problems of multi-purpose scheme studies, is further discussed below.

(c) Other evaluation problems concern the prediction of technical change and the possibility of inflation. Traffic benefits provide an illustration of the first. It is necessary to be able to distinguish between benefits resulting from the crossing and benefits from other road investments. Effectively, this has been done by relating the crossing to a notional "1981" road system, with and without a third Mersey crossing. This procedure is not free from ambiguity but is unlikely to be seriously misleading. Also, traffic flow predictions are related to population growth in a fashion that almost certainly underestimates the potential of technical change in the field of transportation during the next thirty years.

(d) Inflation is an irrelevance. The concern of the study is to establish the real return on investment and this is not affected by changes in the general price level, nor would incorporation of such changes into the exercise alter the relative merits of different schemes. The calculations, therefore, have been carried out at constant (current) prices.

(e) The economic information used, given the need to avoid undue speculation and publicity, is bound to be derived from published sources and to be in part impressionistic. These and other deficiencies are mentioned in the report in no spirit of complaint or apology. Indeed, the relative cheapness of this type of appraisal procedure is considered to make it a valuable tool for ensuring efficiency in the use of public money.

(a) It is conceptually possible to impute the costs of multi-purpose schemes to benefits of particular kinds only if the relevant costs and benefits can be identified as incremental. For example, it is possible in principle to isolate the benefits and costs of adding to a given scheme further water storage on reclaimed land. Apart from such "incremental" possibilities there is no plausible method of allocating scheme costs to particular types of benefit.

(b) Superficially attractive methods, some based on allocations pro-rata to the capital investments needed to gain similar benefits from separate schemes for each purpose, have been suggested but none can give acceptable allocations for the Dee schemes, which include many non-imputable benefits and costs. (Typical of the dangers inherent in cost allocations are extravagant claims, prevalent in some literature, for low-cost desalted water from combined power and desalting plants).

(c) Any method which derives the cost of one benefit as a residual (by deducting costs imputed to other benefits) is dubious in the absence of any direct means of costing the other benefits. Consider a set of single-purpose schemes for each benefit and providing in total the same group of benefits as one multi-purpose scheme. There would be internal consistency in the above exercise only in the unlikely event of the costs of the separate schemes summing to the cost of the multi-purpose schemes. In any event, single-purpose schemes are difficult, in some cases impossible, to devise especially without differential effects, e.g. on amenity.

(d) On the other hand, it is the purpose of the report to guide policy decisions and, with this in mind, absolute consistency of approach need not be an overriding aim. Given that the results may be read by different authorities and for different purposes, it is sensible to try to provide data in a form that each group might find useful.

(e) Thus, it is hoped that an economist reading the report would be satisfied with the coherence of the underlying assumptions and procedures, accepting the need for the various techniques of evaluation adopted. At the same time and despite the foregoing conceptual and practical difficulties, it is important from an engineering point of view to try to provide information in a form broadly comparable to that available for other water or traffic schemes. The various studies attempted do enable maximum costs to be imputed broadly to particular benefits, within the general limits of accuracy of the Phase I study. These costs are £25m for traffic and £20m for raw water conservation, the costs derive from "pure" schemes for these purposes and sum to more than the cost of a multi-purpose scheme (less the costs of water treatment and transmission).

#### 4.5 Multi-purpose schemes - problems of consistency (cont'd)

(f) Again, it is understood that the yield of a toll is a matter of interest and a forecast has accordingly been made in relation to a middle-zone crossing. The results, however, have no place in the benefit-cost calculations since, in a situation in which bridges and roads are generally free of tolls, the yield of a toll on a particular bridge does not provide satisfactory information about the benefit accruing to the community from the existence of that bridge.

(g) Finally, it has already been explained that different valuation procedures have been adopted in respect of different types of costs and benefit. This is unavoidable but involves inconsistency. The most important example concerns the treatment of "transmission" costs in the case of the traffic and water studies respectively. In the case of traffic the benefits of a crossing have been measured in relation to a standardized "1981" road system. Although the costs of the investments needed to produce that system are not included, there is no double counting, since it is also the 1981 system which provides the basis for benefit-evaluation. But the result is that crossing benefits are calculated by reference to a hypothetical road system, in that the calculations assume that road investments which now exist only in plan will in fact have been made before 1976.

#### 4.6 Choice between schemes

(a) So far, discussion has been concerned with the problems of finding appropriate measures of benefit and cost. It remains to present the information, in respect of each scheme studied, in a form that best aids the policy decision.

(b) The first step is to use the discounted-cash-flow technique to reduce the streams of benefits and costs through time to a present value, so recognizing the fact that a pound today is worth more than a pound tomorrow. A decision thus has to be taken as to the interest rate to be used. There has been much discussion among economists as to the possibility of establishing a "social rate of time discount", appropriate for public projects of this kind. No positive view has emerged and there is some reason to believe that none will. The question is in any case of academic rather than of practical interest, given the inevitable margins of error involved in obtaining the numbers to be discounted. A rate of eight per cent has been adopted, on the understanding that this is the rate currently being used in other studies.

(c) It is not uncommon to express the present values so obtained as ratios and to rank schemes by the results. This procedure has certain deficiencies as a policy guide and these are of such importance in the case of this study that to provide such ratios would have been quite misleading. Accordingly, only the relevant present values are given as totals.

(d) In the first place, the use of a discount rate is itself a means of ascertaining what schemes are acceptable, in that any scheme with a benefit-cost ratio of more than one has "passed the examination". Admittedly, this is unrealistic, in that it is unlikely that a government will find itself willing to commit resources to all public uses that pass the test. It raises doubts however about the value of the ratio and there is also room for debate as to which of several ratios is most appropriate.

(e) More important, indeed fundamental from the present point of view, is the fact that the different schemes not only involve different sizes of initial investment and operating costs but they are also mutually exclusive. Thus a separated-purpose crossing scheme might show a "better" ratio, on any measure, than a scheme incorporating water supply. The relevant difference between the two types of scheme, however, concerns the loss, implied by water supplied from an estuary scheme and by other means. From the viewpoint of the community, it is the need to replace this water by investment elsewhere that is important, and not the difference in "ratio" between a road scheme and a more broadly multi-purpose scheme. It may be noted that some part of a multi-purpose scheme is always likely to show a better ratio than the whole scheme, simply because the different types of benefit are averaged in the ratio for the latter.

(f) It is also important to bear in mind that the study attempts to avoid any spurious appearance of accuracy in the evaluation of benefits. There are some benefits (such as the improvement of amenities) that are manifestly real but for which valuation in money terms must be subject to large margins of error.

(g) Such benefits frequently derive from what have come to be known as "public goods". They are benefits which must be enjoyed (consumed) in common and cannot be evaluated by normal market criteria. Thus, a loaf of bread consumed by one man is denied to another. The allocation of loaves between people can be carried out by a market. The market excludes those unwilling to pay enough and prices (values) emerge in the process. But one man's enjoyment of a skyline or shoreline need not deny a similar enjoyment to others. The benefit may be real and indeed important, in that people would be willing to pay if a way to charge them could be found. But it cannot be evaluated directly by using the same "principle of exclusion" as operates in the market for bread. Thus the study does not attempt to evaluate benefits or costs of this type but simply directs attention to those that might be considered relevant.

(h) A final and important reason for avoiding any mechanical interpretation of the results lies in the need to take account of uncertainty. Any attempt to forecast the future involves guesswork and the margins of possible error may be large (as for example in the forecasting of

#### 4.6 Choice between schemes (cont'd)

population). The implication of this, for public as for private investment, is that the ability to postpone commitments (that is, avoid risk) is itself a benefit. In the case of the present study, the benefit-cost calculations take no account of the differential risk-characteristics of different schemes. Other things being equal, however, a staged scheme must be considered superior to one requiring an initial commitment to the whole investment, not only because of the savings implied by the fact that some capital expenditure can be deferred in time, but also because some expenditure need not be undertaken at all should the initial forecasts come in time to be regarded as misleading. This consideration has helped to dictate the form of the schemes presented. It is also a powerful argument against interpreting the alternatives solely in terms of their quantified benefits and costs.

#### 4.7 Suggestions for interpretation

It is the tenor of the foregoing discussion that there can be no substitute for final evaluation of the different schemes by those taking the decisions; a benefit-cost study can guide those decisions but cannot be expected to remove the need for judgment. With this in mind, it may be valuable in conclusion to summarize the important considerations that need to be remembered when interpreting the results:-

- (i) No account is taken of the possible stimulation of the North Wales area by a crossing. This is important not only as a general matter (in that benefits may be undervalued) but because it may bias the choice between schemes.
- (ii) The benefits of an outer line may have been relatively undervalued, in that such a line would be somewhat better suited to the development of commuter and other rail facilities and has more considerable land reclamation possibilities. It is unlikely that any such underestimate would be important enough to offset the many disadvantages of the outer line listed in part 3.
- (iii) Some benefits are listed but not valued. The cost of not delaying provision of a mere is assessed and may be thought relevant to policy.
- (iv) Distributional considerations are ignored, although the mode of finance might affect the generation of benefits. This is thought unlikely to operate differentially between schemes.
- (v) The valuation procedures may undervalue water benefits relative to those from traffic, given the different treatment of related investment. This emphasizes the need

4.7 Suggestions for interpretation (cont'd)

to judge the schemes incorporating water supply by reference to other water schemes and not simply by the quantified benefits.

- (vi) The benefit-cost information gives no weight to risk-avoidance and so understates the relative merits of staged schemes.

5.1 MARINE WORKS

5.1.1 Foundations

(a) The foundation conditions in the estuary have been investigated by a search of the geological literature, an appraisal of the historical changes of the channels, a study of the boring records made for the Central Electricity Generating Board and the National Coal Board and a site investigation carried out specially for this study. Bed samples were taken by the Hydraulics Research Station as a part of the field work for the model tests.

(b) The geological inferences and the site investigation results are summarized in appendices B3 and B4 respectively.

(c) On most embankment lines in the estuary, little material need be removed before starting construction. The foundations for the embankments built on the existing salt marshes however, would have to be stripped of up to 2 ft of silt. The underlying sand might require compaction in places if further investigation confirmed areas of potential instability and the possibility of flow slides. An allowance for some compaction by blasting has been made in the estimates.

(d) The most important aspect of the foundations is their permeability. Generous filter drains would be provided at the toes of all embankments. They would be designed to collect seepage and prevent sand boils and piping. Generally there is a deposit of more gravelly material underlying the estuarine sand. Where this is permeable and at a shallow depth seepage could emerge clear of the downstream toe and cause piping by-passing the drains. Any extensive areas of this nature would be revealed by further site investigation and measures (e.g. drainage wells) would be taken to control the seepage.

(e) The estuarine sands are expected to have an over-all permeability of  $10^{-3}$  cm/sec. or less. In the fully developed pumped storage schemes more than half the length of the enclosing embankments would have drainage ditches on the lower side to lead water back to the pumps. Using the value of  $10^{-3}$  cm/sec. for permeability, the seepage water that would have to be repumped is estimated to be about 5 mgd while that which would drain to the sea and be lost would be about 10 mgd. The cost of repumping seepage water has been allowed for in the estimates of annual running costs. The present valuation of water would not justify the cost of an impermeable membrane, to avoid this low-head repumping or to prevent other seepage losses to the sea.

### 5.1.2 Construction

(a) The presence of extensive deposits of uniform sand and the low cost of dredging and pumping this material would have a great influence on the choice of cross section for the embankments. Some of the sections on which estimates have been based are shown on drawing 17. The details of the section are directed towards the process of getting the sand into place and protecting it once there.

(b) In deep and slow-moving water, parallel mounds of boulder clay, mine waste or rock spalls would be dumped to contain sand pumped between them. The underwater bunds would be built 5 or 6 ft high at a time and the whole embankment brought up in lifts.

(c) Where an embankment emerged above water level or was being built on a drying bank the containing bunds would have to be more substantial to resist wave action until the section was given its final protection of rip-rap or asphalt. In exposed locations the containing banks would have to be built to the full height of the tidal range to prevent storms removing the unprotected sand between them.

(d) Above the level of wave attack, however, containing banks of clay or rock would be unnecessary. The sand itself would be dozed up, as it was discharged from the pipeline, to form its own banks. (In this way embankments can be formed with side slopes as steep as 1 on  $1\frac{1}{2}$  to a considerable height). As the sand dried out, it might be blown by the wind and measures would have to be taken to stabilize it as soon as possible.

(e) In underwater or half-tide work where velocities were greater than about 6 ft/sec., the foundation sand would scour from the toe of the containing banks unless it was covered by fascines or equivalent protection (chapter 5.6).

### 5.1.3 Closure

(a) The method of closure proposed is based on recent experience in Hong Kong and a study of methods used in the Netherland and elsewhere. Sand-fill embankments would be built leaving a closure gap. On the line of the bank the bottom would then be covered with fascines or an equivalent protection and a rock mound would be tipped on top so that its crest was raised uniformly over the whole gap. Scour would tend to occur at the edge of the protection due to the flow over the weir formed by the rock mound but, providing the protection was extensive and flexible enough, the stability of the rock mound on its sand foundation would not be affected. Pending the results of model tests, allowance

### 5.1.3 Closure (cont'd)

has been made for sufficient protection to cover the side of scour holes reaching to the underlying boulder clay or bed rock or three times the depth of water as applicable.

(b) In deep water the rock mound would be started by dumping from barges but, as the crest was raised above low water level, another method would have to be used because of the strong currents which would develop. For closures in the upper or middle estuary and possibly also in the lower estuary, a temporary bridge would be built on piles jettied into the sand to a depth below any expected scour and the rock would then be tipped from dump trucks. If closure of the lower estuary was required further studies might show that the exposure and depth of water were too great to use this method, in which case a cableway<sup>133</sup> would be a practicable though more expensive method.

(c) The tidal sluices would be used to ease closure of the gravity storage impoundment i.e. the balancing basin in pumped storage schemes. They would be built first, within a cofferdam formed by temporary encircling banks. On completion the cofferdam would be removed and water would be allowed to pass freely through the sluices. The embankments on each side would then be built and when the closure gap came to be formed the tidal flow to be staunched would be much reduced because of the bypass provided by the sluices. The water level upstream would follow the tide level at first but as the rock mound was brought up the mean water level would tend to rise. The amount of rise would depend upon the storage volume and the capacity of the sluices. With the balancing basin capacity proposed for pumped storage schemes this rise would not be significant but, with a large gravity storage, the rise could affect land drainage upstream during the period of closure. Temporary extra sluices could provide a solution or temporary pumps could be installed at drainage outfalls. The rock mound method of closure would be used alone for embanked reservoirs where no sluices were available.

(d) When the rock mound had been brought up to high water level a filter would be formed on the upstream side, followed by pumped sand, to bring seepage into line with that of the remainder of the embankment.

(e) Methods of closure are discussed further in appendix D4.

#### 5.1.4 Wave protection and freeboard

(a) The slope protection and crest level of embankments exposed to the sea would be designed to allow for wave action with high tides and north-westerly storms. The amount of overtopping allowable would depend upon its effects and upon the cost of reducing it. The criteria proposed and the influence of frequency of high tide levels, allowing for storm surge or wind set-up, together with the heights of waves and run-up, are considered in appendix D5, where the existing sea defences in the area are also reviewed. Conditions in the lower estuary, with deeper water and a more open aspect, would be more severe than in the upper estuary. Similarly, conditions in the centre would be more severe than at the sides.

(b) Typical crest levels for embankments where seaward freeboard governs, as used for the cost estimates, are as follows :-

Position in estuary	Centre	Sides
Lower estuary	33 ft O.D.	29 ft O.D.
Mid-estuary	29 ft O.D.	25 ft O.D.
Upper estuary	25 ft O.D.	23 ft O.D.

(c) Levels for the sides correspond generally with the highest existing sea defences in the area. Centre levels are higher in the more exposed and deeper water. Some revisions might be needed in Phase II following further study.

(d) The following criteria were used for calculating these levels. In the long term, say 1000-year return period, there would be no danger of a breach. In the short term overtopping would be by less than 1% of waves in a one hour period recurring on average once in 10 years. The frequency of overtopping could be expected to reduce in time due to sediment accretion in front of the banks. Spray from breaking waves would be blown over the embankments by high winds. With the slopes proposed the amount of spray would be moderate but could occasionally affect traffic on a crossing. To minimize spray (and for aesthetic reasons) a wave wall would not be used. However, where freeboard on the seaward side governed, the road would be built lower than the crest to save fill material. With a difference in level of up to 5 ft, any percolation through the seaward rip-rap bank to the road verge during wave run-up would drain away during the interval between highwaves.

#### 5.1.4 Wave protection and freeboard (cont'd)

(e) For slope protection a design for waves corresponding to winds of 50-year return period is proposed. Minor damage could be expected under storm conditions more severe than those designed for but this could be repaired later.

(f) Rip-rap, consisting of graded stone quarried in the local hills would be the most suitable form of wave protection. Laid with a filter layer beneath, it would be flexible and would be self-healing in the event of local damage. It would need little maintenance or repair.

(g) The side slopes chosen would be largely governed by the design of protection rather than by stability. The cheapest combination of slope and rip-rap thickness would be selected. A slope of 1 on 3 and thicknesses varying from 1½ ft to 5 ft depending upon exposure have been used for estimating. Due to changing techniques and prices for materials, the proposals should be re-examined nearer the time of construction. In Phase II a detailed study of the frequency of occurrence of large waves and the risk of damage with different grading and thickness of rip-rap should be undertaken and supplemented by model tests and wave observations. The use of other materials such as asphalt should also be re-examined.

#### 5.2 ROADS AND BRIDGES

##### 5.2.1 Design criteria for estuary crossings

(a) The traffic flows throughout the Wirral are urban in character and the proposed Mid-Wirral Road has been regarded as an urban motorway.

(b) In view of the expected increases in traffic flows across the estuary and because a demand would develop on a crossing by commuter traffic between North Wales and Merseyside, it is considered appropriate to adopt urban criteria in appraising the capacity of a crossing.

(c) Peak hour traffic flows of the order of 10% of the daily (16-hour) flow are common on roads in the southern part of the Wirral and apply to cross-Dee traffic flow at Queensferry. This percentage is unlikely to be less in the future and is therefore used for design purposes.

## 5.2.1 Design criteria for estuary crossings

(d) To convert cross-Dee traffic flows of vehicles per day into passenger car units a conversion factor of 1.25 is adopted. This is somewhat less than might seem appropriate from a classification of traffic on main roads in Flintshire (see appendix E3) but is higher than factors applicable throughout the Wirral.

(e) Approximate peak hour flows (one-way) in passenger car units are obtained from the daily (16-hour) two-way flows tabulated in appendix C4 for the three reference years (assuming a third Mersey crossing) as follows :-

Estuary crossing	1962		1981		2001	
	16-hr. v.p.d.	peak hr. p.c.u.	16-hr. v.p.d.	peak hr. p.c.u.	16-hr. v.p.d.	peak hr. p.c.u.
Middle zone crossing	23,200	1,450	41,000	2,560	62,000	3,880
Crossings in middle and inner zones together	(m) 21,200	1,330	37,800	2,360	57,200	3,580
	(i) 6,600	420	13,600	850	22,400	1,400
Combined middle/inner zone crossing	34,400	2,150	60,800	3,800	93,600	5,850

(m) denotes middle zone

(i) denotes inner zone

(f) It is recommended that full motorway design standards be adopted for the crossing between the proposed interchange with the existing route B.5332 west of Holywell and the proposed connections with the Mid-Wirral Road. A design speed of 70 m.p.h. is considered to be appropriate for the crossing, with grades not exceeding 4% although, on the Flintshire side, a limited use of 5% grade is avoidable only at the expense of much more earthworks.

(g) Although it is considered that motorway design standards should be used, the crossing should not necessarily be classified from the outset as a motorway.

### 5.2.2 Staged construction of roadworks

(a) From the estimated peak hour flows tabulated in section 5.2.1 it is possible to determine the capacities of the crossings, in terms of the number of traffic lanes required between the earliest date that a crossing is first opened to traffic, (which for this purpose is assumed to be 1976) and the end of the present century, employing criteria for free flow of 1,500 p.c.u. per hour per lane for roads to motorway standard and 1,200 p.c.u. per hour per lane for all-purpose dual-carriageway roads.

#### Middle zone crossing (schemes W, X or Z)

(b) This crossing alone could operate effectively with dual two-lane carriageways, as an all-purpose road up to 1980 and as motorway up to 1987, thereafter it would require dual three-lane carriageways.

#### Crossings in middle and inner zones (schemes XX or ZZ)

(c) If the inner zone crossing were opened to traffic by 1981, the middle zone crossing could operate effectively as a dual two-lane all-purpose road until 1983 and thereafter as a dual two-lane motorway until 1991. Traffic flows indicate that the inner zone crossing would be needed by 1987 unless the middle zone crossing had been improved to dual three-lanes by that date.

(d) The traffic flow estimates for the inner zone crossing alone, however, (table 2, appendix C4) indicate that it would require dual two-lane carriageways at once (1976) and that these would suffice only up to 1981 when they would need to be augmented by further lanes or another crossing.

#### Combined middle/inner zone crossing (scheme Y)

(e) This crossing would require dual three-lane carriageways at the outset. By about 1988 dual three-lane carriageways would be inadequate for this crossing scheme and dual four-lane carriageways would be required in the absence of further cross-Dee facilities for road traffic unless, as seems likely from e.g. diagram 14 of drawing 12, some re-distribution of traffic between the new crossing and Queensferry were to occur. (The Phase I study could not take such re-distribution into account - see appendix C5 paragraph (c)).

(f) In any event, an alternative for testing in a more refined study would be to replace link DF by a link EF, thereby reducing the traffic flow on ED. A further refinement would be to consider an alternative

### 5.2.2 Staged construction of roadworks (cont'd)

alignment for GE to the north of Neston, especially if interchange G would be better sited nearer K than is shown, e.g. due to implications of a third Mersey highway crossing in the conurbation area.

(g) The branch EG of the Wirral approach to this crossing would require dual two-lane carriageways at the outset and this would suffice until about 1985, after which dual three-lanes would be needed.

(h) The branch EB to Shotwick would suffice as a single two-lane carriageway all-purpose road until about 1980 and as a dual two-lane carriageway road until the end of the century.

(j) The length of proposed new road NUD parallel with the Flintshire shore would require dual two-lane carriageways to motorway standard by 1980 and this would suffice also until the end of the century.

### 5.2.3 Improvements to adjoining roads

(a) Westward of the proposed interchange at H in Flintshire, the trunk road A.55 is scheduled for improvement during the next ten to fifteen years, including dual two-lane by-passes to St. Asaph and Abergelle. Improvement throughout to this standard would appear to be adequate during the present century.

(b) Route B.5332, which would cater for cross-Dee traffic to Rhyl and Prestatyn, would require dual two-lane carriageways by 1981 in association with a middle zone crossing (see diags. F8 and F9, drawing 11). Prestatyn traffic using a combined middle/inner zone crossing would evidently prefer to use the coast road A.549, in which case route B.5332 need have no more than an improved single two-lane carriageway.

(c) The implications (of cross-Dee traffic) for the Mid-Wirral Road are clear from the traffic flow line diagrams. Similarly, the likely relief of congestion at Queensferry is apparent from a comparison of the flow line diagrams for any year.

### 5.2.4 Bridges

(a) For a road crossing scheme alone in the middle zone (scheme W), the crossing would be by a viaduct, some twenty-five thousand feet in length, with a main span of the order of three hundred feet. A headroom of fifty feet over high water level might be adequate, although this is a matter for further study.

#### 5.2.4 Bridges (cont'd)

Although it would detract from the crossing facility (compared with an embankment crossing), somewhat narrower shoulders and central reserve have been considered for the road on the viaduct. A separated walkway would be provided on one side.

(b) Bridgeworks forming part of a multi-purpose scheme would be much less in extent than envisaged for scheme W and would be unlikely to exceed three thousand feet over all.

(c) Certain safeguards would have to be observed to prevent scour affecting the bridgeworks but, otherwise, from the results of the borings carried out in Phase I, foundation problems would be unlikely to be unduly troublesome for structures of the magnitude envisaged. A more detailed description of bridge types and materials is not warranted in Phase I.

#### 5.3 WATER SUPPLY

(a) Water would be drawn from the trained channel within the balancing basin (chapter 5.5) which would stretch, effectively, from Chester weir to the sluices giving a balancing capacity of 500 mg with a range of levels from +3 to +7 ft O.D. Water levels would reflect the flow in the river, the amount of abstraction and, during spills, the state of the tide.

(b) Depending upon details of the scheme adopted and the stage of development reached, one or more low lift pumping stations, founded on piles, would be built to abstract water for storage from the trained channel. The pumping capacities required are given in appendix D1. Because of the advantages for water quality control (appendix D3) facilities to pump into any one of the several reservoirs would be provided and delivery pipelines or channels would be required in some cases.

(c) Storage capacity would be virtually unaffected by suspended sediment abstracted from the river (from preliminary estimates 5000 years would be needed to fill the reservoirs with sediment - appendix D1). Yet should dredging be found desirable and economic in the future, the availability of several impoundments would enable the quality of water drawn off to be maintained while work was in progress.

(d) Spillways would be provided for each reservoir to permit overflow due to rain on the water surface or in the event of pumped inflow failing to stop after the top water level was reached.

### 5.3. Water supply (cont'd)

(e) A draw-off structure in each reservoir with two draw-off levels would be situated well away from the point of inflow. Long draw-off pipes would be needed in some cases to take water to the treatment works where booster pumps would provide the head required for flow through the works.

(f) A position for the treatment works on reclaimed land below Neston would be suitable for any of the pumped storage schemes. Enough land would be reserved for an ultimate capacity of 300 mgd, or even more, but construction would probably be in stages of 50 mgd each. The best layout for staged construction (e.g. for linear or radial expansion) would be studied in Phase II. Flexibility not only to match demand but to cater for future improved treatment techniques would be the aim. A high ground-water table might exist requiring provision against flotation in the design and for foundation dewatering during construction. The treatment tentatively proposed and for which provision has been made in the estimates is given in appendix D3.

(g) A high lift pumping station next to the treatment works would deliver water to supply areas. Detailed design of pumps and delivery pipe sizes would have to await a decision on the areas to be supplied (chapter 2.3). The estimates do not include for the cost of service reservoirs or local distribution works.

### 5.4 LAND RECLAMATION

#### 5.4.1 Enclosure

Embankments enclosing reclamations would be generally as shown on drawing 17 and described in chapter 5.1 but the rip-rap protection would be replaced by topsoil and grass on the landward side.

#### 5.4.2 Drainage

(a) Drainage of the enclosed areas would be by tidal flap gate, unless low-lying areas were reclaimed when some pumping would be needed. A system of drainage channels and ditches would be constructed to control the ground water table. They would lead to balancing ponds upstream of the tidal outlets to allow for intermittent discharge, at low tide. Subject to adequate water quality, the run-off from some areas could be directed to the flood balancing basin to increase water conservation.

#### 5.4.2 Drainage (cont'd)

(b) The ground water table could be quite high for pasture land but would need to be lower for other uses. By siting any building development on the higher ground with deeper drainage channels, control could readily be exercised. The level of some land reclaimed might be raised before or after enclosure, by pumping dredged sand from offshore.

#### 5.4.3 Soil quality

(a) The material occurring at ground surface in the reclamations would vary from very fine sand and some silt in the upper parts of the estuary to fine sand elsewhere. In general the finer material could be expected to acquire a vegetative cover quite rapidly, indeed vegetation is already well established on the saltings. However, fine sand occurring without a covering layer of silt would be subject to wind erosion and, in time, would form dunes unless preventive measures were taken. Special techniques such as mechanical spraying of a mixture of seed and mulch of wood fibre or latex solution might prove useful.

(b) After grass had grown for a few years and most of the salt in the ground had been leached by rainfall, agriculture could be established in areas where sufficient silt content would prevent wind erosion after ploughing. Physical and chemical tests of samples of typical bed material in the estuary have shown that, with generous fertilizer applications in the first few years, grade II to III agricultural land would be expected at a reasonable cost of conversion.

### 5.5 FLOOD PREVENTION

#### 5.5.1 Floods

(a) As discussed in appendix D1 the design flood has been taken as a peak flow of 30,000 cusecs at Chester. It has been derived from flow measurements at Erbistock gauging station with allowance for the catchment downstream; the risk of occurrence is estimated to be low.

(b) Accurate correlation with Erbistock records has not been found possible, using the tentative rating curve now available and even after making due allowance for the flood balancing effect of the washlands upstream in combination with the flow constraints at bridges. In Phase II, Chester weir should be rated at high flows to enable water level records to be used for improving flood estimation.

### 5.5.2 Canalized section

(a) When the river was canalized between Chester and Connah's Quay the bed level was excavated to about 0 ft O.D. Sediment from the estuary has gradually accumulated, in spite of dredging in the past, until the average level now is about + 4 ft O.D.

(b) There is a danger that the coincidence of a large flood, similar to that of December 1964 or greater, and an abnormally high tide level might overtop the banks of the canalized reach below Chester.

### 5.5.3 Balancing basin

(a) With any of the multi-purpose schemes illustrated, a balancing basin having a flood balancing capacity of 4,000 mg would be provided. Sluices would control the outlet and prevent inflow of sea water at high tide and their capacity would suffice to pass a river flood of 30,000 cusecs easily. Flood water ponded in the basin at high tide would be discharged later with little head loss.

(b) On a falling tide the water level in the basin would be only marginally higher than tide level and thus existing land drainage arrangements into the basin would be virtually unaffected. On a rising tide the level in the basin would lag behind tide level even under design flood conditions and a marginal improvement in land drainage could therefore be expected. With a mean annual flood, a maximum water level of about + 10 ft O.D. would occur during high tide. This level, which corresponds approximately to the level now reached in this part of the river during neap tides, would be an improvement on the conditions during spring tides now. With a design flood and a tidal surge to + 20 ft O.D., however, the water would rise to a maximum level of about + 18 ft O.D. and it would back up in the canalized reach. By also dredging in the canalized reach to 0 ft O.D. risk of overtopping of the banks near Chester would be avoided, and this has been allowed for in the cost estimates together with some extra toe protection to the banks. The opportunity might be taken to complete the embankment protection works which have been started by the River Authority.

(c) In the past, dredged parts of the channel have shoaled rapidly. A preliminary estimate however, indicates that the sediment load carried by the river is quite small (appendix D1) and it is concluded that the shoaling was largely due to sediment transported from the estuary by the tides. With tidal sluices this would be prevented and, allowing for the scouring effect of floods flowing down the channel at low tide, no difficulty is envisaged in maintaining a stable bed level at 0 ft O.D. Support for this view is given by the stability of the bed level which remains at only a few feet O.D. for some 10 miles upstream of Chester weir.

### 5.5.3 Balancing basin (cont'd)

(d) The embankments forming the balancing basin would be built to at least + 20 ft O.D. Operating water levels, however, would normally vary between +3 and +7 ft O.D. and training banks built to +8 ft O.D. would constrain the river to a channel in continuation of the existing canalized section as far as the sluices. These banks, being built of rockfill and similar to the existing half-tide training wall, would be permeable and could be overtopped without damage.

(e) Outside the trained channel there would be an area of water to the +8 ft O.D. contour beyond which would be water meadows subject to occasional flooding. Grazing of this land could probably be allowed provided that warning was given to the public, by notices, that a rapid rise of water level could occur. The whole basin could form a nature reserve.

(f) The size of balancing basin, the backwater effect at Chester and the stability of the bed level in the canalized section should all be re-examined in Phase II in conjunction with model tests.

### 5.5.4 Chester weir

Provision of a balancing basin in the upper estuary would make the installation of a sluice beside Chester weir a possibility worth further study. The water level immediately upstream of the weir could be maintained at crest level for flows up to 3 or 4 times the average. Pumping would be reduced for those land drainage schemes already started and others might prove unnecessary as a result.

## 5.6 MATERIALS AND CONSTRUCTION

(a) The main constructional materials for embankments i.e. sand, boulder clay and mine waste, occur in and around the estuary. Their properties and use are described in appendices B3 and B4 and chapter 5.1.

(b) Rock would be required in large quantities for closure, permanent wave protection, road works and concrete aggregate. There are several possible sources of rock. Carboniferous Limestone can be quarried in large blocks and would make an admirable source of rockfill. Blocks 3 feet in size have been used as protection at Greenfield Harbour. Cefn-y-Fedw Sandstone is massive and suitable for rockfill. Gwespyr Sandstone is probably unsuitable as fill due to its tendency to break easily along comparatively closely spaced bedding planes. A few beds of coarse hard sandstone occur in the coal measures and one such bed has been quarried at Mostyn; this material could be used as rockfill but the problem would be to find enough at any one location. Bunter rocks have

been used throughout the Wirral as building stone but enough hard coarse sandstone may not be obtained economically due to the variations that occur.

(c) The best source or sources of rock would have to be investigated further in Phase II but, for the estimates, use of carboniferous limestone from the Halkyn mountains has been assumed.

(d) Where maximum protection against scour is required (e.g. during closure) special techniques would be used. Fascine mattresses are the traditional material, particularly in East Anglia and in the Netherlands. They consist of layers of brushwood and reed bound together and weighted with stones. The thickness of the layers and amount of stone can be varied to suit site conditions. They are particularly suitable for scour protection because, being pliable, they can accommodate settlement or erosion of the underlying material without rupturing. Being rough they also reduce scour velocities. However, because of labour scarcity, alternative methods more amenable to mechanization are being developed. For example, hot mastic asphalt can be poured under water to grout the voids of a stone mattress. Sand asphalt mastic revetments can also be placed under water. Nylon fabric mattresses have been used and gabions filled with quarry waste would merit further consideration. The present estimates allow for use of fascines but tests would be made before final designs were prepared on various types of protection.

(e) In Phase II, various other aspects of construction would be studied further, including :-

- (i) a review of the contractors who might tender for the work to assess the resources of skill, plant and labour available and hence the desirability of subdividing the work (e.g. estuary work/approach roads);
- (ii) the need to let minor contracts for initial works (e.g. access roads);
- (iii) a detailed programme for the first stage;
- (iv) the most suitable location for temporary facilities including temporary roads, harbours and buildings such as offices, plant yards, workshops, housing and labour camps;
- (v) incidental effects such as extra-ordinary traffic and interference with local activities and amenities.

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	*H. R. Bollington	Welsh Office
	*J. R. Forshaw	Department of Economic Affairs, N. W. Region

\* also serves in Liaison Group

DEE CROSSING STUDY  
Terms of Reference for Phase I

The Consulting Engineers are asked to carry out and complete the following within a period of 9 to 12 months from the receipt by them of formal instructions to proceed.

1. A preliminary appraisal of the practicability of a Dee crossing from the engineering and hydrographical point of view bearing in mind data already available from previous studies of the estuary. (See also paragraph 3).
2. A preliminary appraisal of the viability of a crossing, of the form it should take and the probable optimum siting having equal regard to :-
  - (a) the possibility of land reclamation for agricultural, residential, industrial, open cast coal working or other purposes;
  - (b) water conservation;
  - (c) improved communications and consequential developments;
  - (d) improvement of port and navigational facilities;
  - (e) other possible consequential benefits and effects in relation to land drainage, sewerage and other outfalls, fisheries (sea and freshwater), prevention of tidal flooding, coast protection installations and any other benefits or effects which may come to the attention of the consultants;
  - (f) preservation and improvement of coastal amenities.

Such appraisal to include an appreciation and a preliminary cost/benefit study of the effect of a crossing on land use and traffic flows on each side of the Dee Estuary.

3. Boring and seismic studies in the estuary adequate to give a preliminary assessment of the engineering practicability of a crossing on one or more of the suggested lines for the crossing, this to be subject to a programme to be agreed with the Minister.

4. A preliminary assessment of the need for a mathematical model to determine tidal effects on adjoining estuaries and coastline.
5. An assessment of the scope, cost and duration of Phase II of the feasibility studies.
6. A full report of the results of the investigations and the conclusions reached in Phase I.

The Consulting Engineers are asked to submit to the Minister a detailed programme of the studies and to provide brief monthly progress reports as the work proceeds.

SCHEME OBJECTIVES

The main factors suggested as influencing a qualitative comparison of alternative schemes are set out below but are not in any order of priority:-

GENERAL

- (1) The scheme should be a sound and socially desirable development of the estuary, adjoining land and river resources, viewed as far in the long term as possible.
- (2) The engineering should be practicable.
- (3) The scheme should be suitable for staged development and produce early returns/yields.
- (4) The scheme should be economic and attractive for public investment as expressed by the sum of all social and economic net benefits.

COMMUNICATIONS

- (5) The transport facilities provided should fit national road (and rail) systems and contribute to the solution of regional and local traffic problems in respect to :-
  - (i) existing or planned highway networks e.g. in Liverpool, the Mersey crossings, the mid-Wirral road and the Chester ring road;
  - (ii) providing improved communications for industry (e.g. Flintshire and N. Wales to Port of Liverpool), commuters, holidaymakers and others wishing to cross the estuary;
  - (iii) reducing congestion, e.g. Queensferry, Chester, Flintshire coast road.
- (6) Navigation, e.g. at Mostyn port and towards Chester should be maintained if possible.
- (7) Interference with coastal navigation, e.g. at approaches to the Mersey, should be avoided.

WATER AND SEWAGE

- (8) Development of the Dee water resources should be the best possible.

- (9) Facilities should be provided for large water treatment works on reclamation.
- (10) Least extra sewerage and effluent treatment should be required.

#### INDUSTRY, HOUSING AND EMPLOYMENT

- (11) The scheme should create - or enable to be created - the right conditions for growth of new and diverse industry in Flintshire (and N. Wales) by the provision of land and water supplies, housing for labour and management and quick access to ports and existing service industries; and hence attract labour, trade and services, raise existing living standards, allow urban renewal and relieve population pressures elsewhere.

#### AMENITIES, NATURE CONSERVATION AND RECREATION

- (12) Wirral amenities should be preserved and improved.
- (13) Flintshire amenities should be developed.
- (14) New recreation and holiday facilities should be created.
- (15) Nature reserves should be preserved or new ones created, with special reference to birds at Hilbre and tidal flats.
- (16) National Trust amenities should be preserved.
- (17) Some estuary should be preserved as "wilderness".

#### LAND, FLOODING, DRAINAGE AND PROTECTION

- (18) The scheme should involve least use and disturbance of existing property including agricultural land.
- (19) There should be community gain from any land reclaimed.
- (20) Land should be reclaimed for agricultural use (e.g. for sheep) only if economic.
- (21) The scheme should enable flooding of land upstream of Chester weir to be reduced at least marginally.
- (22) The danger of overtopping training walls and of flooding land downstream of Chester weir should be reduced.
- (23) There should be least extra drainage requirements.

- (24) Savings on coast protection works should accrue from the scheme.
- (25) There should be least chance of affecting coastline adversely e.g. from N. Wales resorts to N. Wirral.
- (26) Conditions for any opencast coal working should be improved.

FISH

- (27) Numbers and early runs of migratory fish should be maintained.
- (28) Offshore nursery zones for sea fish and estuary sea fisheries should be maintained.

MODEL TESTS AND STUDIESPART I

(Information in Part I provided by the  
Hydraulics Research Station, Wallingford).

(a) In January 1965 the Dee and Clwyd River Authority signed an agreement with the Hydraulics Research Station for the construction and operation of a model of the Dee estuary at Wallingford.

(b) To obtain a record of the present form of the rapidly-shifting estuary bed, an aerial survey at low water of spring tides was required. From this, contours of the drying banks could be drawn, supplemented by echo-sounder surveys of the low water channels taken by the H. R. S. survey party. The River Authority were to finance the aerial survey separately from the main model investigation, but H. R. S. agreed to draw up the specification for photography and use its knowledge from previous similar work to place the contract. This was awarded in June 1965 to Meridian Airsurveys, who executed the photography on August 17th of that year. Subsequently, they provided a mosaic photograph of the estuary and a set of 6 inch to 1 mile revised Ordnance Survey maps, with over-lays contoured at 2 ft intervals.

(c) The H. R. S. survey group were able to move to the Dee estuary in mid-August 1965. From then until February 1966, as weather and tidal conditions allowed, they observed current velocity and direction, measured salinity and took bed samples at stations seaward and in the entrance of the estuary. Cross sections were surveyed and tides observed simultaneously at points along the estuary. The simultaneous tidal observations were repeated in April 1966, on each occasion with help from the River Authority.

(d) Design work on the model could not advance far before receipt of the survey results but, during the later part of 1965, numerous meetings were attended with other authorities affected by the proposed crossing. Also the model's capabilities were explained to consulting engineers who might advise the Dee Crossing Technical Working Party which was set up in July 1965. By mid-January 1966 the leading points of the model design were decided and floor space had become available in the main experimental hall at Wallingford. Model construction began in late January, to a horizontal scale of 1 : 1500 and vertical scale of 1 : 60, starting with the enclosing tank and water storage sump of in-situ concrete. Within this, the composite model bed was moulded of rigid cement mortar from the seaward limit to the Point of Air - West Kirby line. Within the estuary the shore was formed to spring tide high water line in cement mortar, below which was a vertical face falling to

a horizontal floor at a level well below the greatest expected channel depths. In the basin so formed between high water lines, the selected mobile bed material, granulated bakelite, was placed later and moulded to reproduce a known survey. While construction was proceeding, the main tidal generating pumps and pipework, the tide generator weir gates and control mechanism and the subsidiary fresh water flow pump and metering device were installed.

(e) By early August 1966 the model construction was completed and the estuary was moulded to the aerial survey of 1965 ready for proving tests. The proving was to be in two phases: first to ensure correct tidal propagation along the estuary and secondly to demonstrate bed movements and to confirm the time scale of these indicated in the feasibility calculations. As expected, the tidal propagation tests have taken a long time and were still not quite complete in February 1967. For the earlier tests, various forms of energy dissipation on the rigid seaward approach were investigated, with repeated spring tides, but the more successful later approach was to modify slightly the generated sea tide to give good representation at the estuary mouth. In future tests, a representative succession of tides modulated from spring to neap will be used.

(f) For the tidal propagation tests, any one of which covers a relatively short time in the prototype, there was no injection of extra bakelite on the seaward margin of the rigid approach section to represent bed material moving in the Irish Sea. This facility will be provided for any test of long duration e.g. the channel movement proving and tests of proposed crossing schemes. As an indication of the rate at which bed material should be added to the model, a comparative cubature of the estuary between 1891 and 1965 is being carried out. This will be only a guide, however, to be adjusted if necessary according to the model indications of channel movement.

## PART II - MODEL REQUIREMENTS FOR PHASE II

### Hydraulic Models

(a) The hydraulic model would be used to test the effect on tide levels and sediment in the estuary of crossings and enclosures according to alternative schemes with special reference to the effects upon maintaining channels for navigation and flood releases.

(b) The provisional terms of reference dated June 1965, as agreed between the Dee and Clwyd River Authority and the Hydraulics Research Station, are attached. These provide in items 3(b) to (h) for investigations to be carried out on the effects of a crossing on Matheson's scheme B2 (c), a barrage between Gayton and Greenfield, a crossing between West Kirby and Point of Air and crossings at intermediate locations, with further investigations of hydraulic problems on the selected crossing and of navigable depths of water with port development projects.

(c) In the light of this report, substitution for items 3(b) to (h) of the following is recommended :-

1. Investigations with 1/1500 scale model of estuary in the order stated :-

- (i) prediction of future patterns of accretion with no further estuary works;
- (ii) prediction of water levels to Chester weir with no estuary closure when a high river discharge coincides with a storm surge or wind set-up at high spring tide;
- (iii) prediction of surge levels under various conditions;
- (iv) prediction of the long-term effect on the estuary of a closure on the Flint-Neston line with and without downstream enclosed reservoir and with sluices in various positions;
- (v) prediction of the long-term effect on the estuary of a closure on the Greenfield-Gayton line with and without downstream reservoir and with sluices in various positions;
- (vi) tests of closures on other lines, or of a partial closure, as may be required;
- (vii) tests to determine the best location for the trade waste outfall;
- (viii) tests to establish ways of using tidal and/or river flows to move large amounts of estuary bed material and make construction of embankments cheaper; similar tests of economic ways of producing amenity and landscaping features such as irregular banks and islands.

The main object of (iv), (v) and (vi) would be to determine the probable short and long-term effects of each closure on channel regime, sediment deposit and tide levels in the estuary.

2. Model tests of a method of maintaining a tidal channel open for navigation. This comprises the retention of water in a tidal basin at high tide and releasing it at a high velocity just before low tide. This method is now used at Mostyn on a small scale; whether it would prove satisfactory with a longer outflow channel has to be established.

3. Investigations with models of closure operations. These would be done in a larger scale undistorted model of part of the estuary in order to determine the most economic method of closure and extent of bed and bank protection needed.

4. Investigations of a basic character to determine the height of run-up due to the action of waves on slopes protected by rip-rap. Although some research has been done on this subject there is marked divergence between results, due probably to the variation in thickness and grading of the rip-rap. The question is important in deciding crest levels. Tests are proposed under the specific conditions for embankments in the Dee estuary.

(d) The cost of the 1/1500 scale model has already been estimated at £78,000 and this allocation is not included in the present estimates which include, however, a provisional sum of £50,000 for items 2, 3 and 4.

### PART III - WAVE OBSERVATIONS IN THE ESTUARY

(a) It is important in deciding the crest level of banks exposed to the action of sea waves to be able to estimate the heights and periods of waves in the estuary resulting from deep water waves approaching from the Irish Sea. If calculation methods are used, assumptions have to be made to assess the energy loss as the waves pass through shallow coastal water and along the estuary; most of the energy of high waves may be dissipated and errors could make a big difference in the results.

(b) It is therefore proposed to carry out a programme of simultaneous wave observations, at the mouth of the estuary and at one or more positions near the proposed works. A provisional sum of £12,000 has

been included in the estimate for this purpose.

#### PART IV - MATHEMATICAL MODEL

(a) It is understood that Dr. Rossiter proposes a study of mathematical models for application to barrage problems. It would be designed specifically for the three barrage areas in the eastern Irish Sea, and would receive financial support from the Natural Environment Research Council. The technique of 2-dimensional mathematical tidal models is still in the early stages of development and the project has the aim of establishing the value of this technique in determining tidal effects on adjoining estuaries and coastlines.

(b) The immediate effect of a closure of any estuary would be indicated by the difference in tidal levels and velocities without and with the closure; the results could be used for a study on the long-term effect on littoral drift and sediment movement in the tidal channels. A physical model to produce this information would be far more costly and, although it could throw more light on sediment movement, it would still not provide a complete answer; this is because littoral drift depends not only on tidal currents but also on wave action in shallow water near the coast.

(c) It is not certain, in view of the types of scheme proposed for the Dee, that a mathematical model of the Dee would be needed in Phase II of the investigation. Nevertheless, the potential value of a mathematical model is considerable. Assuming that the study referred to above confirms this view, it is suggested that means be sought for financing an intensive study of the Dee estuary using this technique. The reasonably modest sum of £6,000 would be required and would at least ensure that all available safeguards in investigation had been taken. This figure does not include the cost of taking additional field observations if necessary.

#### PART V - COST SUMMARY

Excluding the £78,000 already allocated for the main hydraulic model, the costs in this appendix are :-

Further model tests	£50,000
Wave observations	12,000
Mathematical model	6,000
Contingencies	<u>7,000</u>
	<u>£75,000</u>

# RIVER DEE INVESTIGATION

Copy of provisional terms of reference  
dated 11th June 1965 for Hydraulics Research Station, Wallingford

Between 1937 and 1956 model studies of the effect of a crossing over the Dee Estuary on the movement of sediment and on water levels, in both estuary and river, were undertaken. The model, with scales of 1:5000 horizontal and 1:200 vertical, simulated the effects of crossings of different types and locations. The results obtained from these investigations are dependable in general, but they should be thought of as a preliminary guide, i.e. as a pilot model study. A larger-scale model is required to establish in more detail the full effects of a crossing. In the model now proposed, certain refinements and improvements will make it possible to obtain more accurate information about the movement of sediment and about water levels, both of which factors effect navigation and land drainage problems, namely;

- (i) larger scales, i.e. a horizontal scale of about 1:1500 (The vertical scale will be of the order of 1:100, but this is subject to further study),
- (ii) the difference between the density of sea and fresh water will be taken into account, and this may well have an important effect on bed changes,
- (iii) sediment will be introduced at the seaward end of the model to simulate the supply of sediment by movement along the coast,
- (iv) the effect of waves can be included if it is considered that they will significantly affect the results, and
- (v) the model will be constructed and operated with the benefit of more accurate, up-to-date and complete hydrological and topographical data.

The programme of field and laboratory investigation which it is proposed to conduct is summarised below:

1. A field survey is to be made in which the following will be measured:
  - (a) cross sections covering the deep channels of the estuary,
  - (b) simultaneous water levels, over both spring and neap tidal cycles, in the tidal reach,
  - (c) magnitudes and direction of currents, both in the estuary and offshore,
  - (d) particle sizes of sediments within the estuary,
  - (e) concentration of suspended solids,
  - (f) salinity, and its variation in space and time,
  - (g) the pattern of bed change within the estuary.
2. An hydraulic model is to be built to a horizontal scale of 1:1500 (subject to review in the light of field data).
3. The following investigations are to be carried out in the model:
  - (a) Prove the model's performance in respect of tide levels, discharges, currents and bed movements.
  - (b) Examine the effects of a crossing between Gayton and Greenfield using an embankment and bridge, in conjunction with training walls linking Connah's Quay to the bridge opening i.e. Matheson's scheme B2(c).

The effects to be studied are :-

    - (i) The movement of sediment on the seaward and landward sides of the crossing, and the resultant shoaling or scouring of the deep water channels.
    - (ii) The redistribution of sediments on the landward side, as affecting the reclamation of land.
    - (iii) The changes in tidal range and in the levels of both high and low water at various points along the estuary.
    - (iv) The changes in the period of flood and ebb tide, for example, at Connah's Quay.
    - (v) The velocities through the bridge opening for various tides and flood flows.
  - (c) Examine the effects (as listed in 3(b) above) of a crossing between Gayton and Greenfield in the form of a barrage for various durations of opening of the barrage flood gates.

Such a scheme would make the inner Dee non-tidal and would permit land reclamation with low retention levels, or water storage projects with higher retention levels.

(d) Consider the desirability of constructing training walls at an earlier date than the crossing.

(e) Repeat investigations 3(b) and 3(c) for a crossing between West Kirby and Point of Ayr, assuming that economic and engineering studies have shown a crossing on such an alignment to be a viable proposition.

(f) Consider the desirability of investigating intermediate locations.

(g) Make a preliminary investigation of hydraulic problems in the construction of the selected crossing. (A larger scale model would be required to study closure if the crossing is to take the form of a barrage, especially if the seaward alignment was accepted.)

(h) Investigate possible port development projects in respect of navigable depths of water with the various schemes considered.

4. A full report on the work will be submitted at the end of the investigation, and interim reports will be supplied at intervals during the investigation when results of importance are available.

LIST OF AUTHORITIES, BODIES & PERSONS CONSULTED  
AND ACKNOWLEDGEMENTS

Ministry of Land and Natural Resources  
 Welsh Office  
 Department of Economic Affairs, N. W. Region  
 Ministry of Housing and Local Government, London & N. W.  
 Region  
 Ministry of Transport, London & N. W. Region  
 Ministry of Agriculture, Fisheries and Food, London,  
 Wolverhampton & Leeds  
 Board of Trade, London & N. W. Region

Freshwater Biological Association  
 Hydraulics Research Station, Wallingford  
 \*Institute of Geological Sciences  
 Meteorological Office  
 National Institute of Oceanography  
 Natural Environment Research Council  
 Nature Conservancy  
 Water Resources Board

British Railways Board  
 British Waterways, Northwich  
 Central Electricity Generating Board  
 Crown Estate Commissioners  
 National Coal Board and Opencast Executive

Cheshire County Council  
 Flintshire County Council  
 Southport Borough Council  
 Wallasey Borough Council  
 Hoylake Urban District Council  
 Neston Urban District Council  
 Prestatyn Urban District Council  
 Rhyl Urban District Council  
 Wirral Urban District Council  
 Hawarden Rural District Council

Dee and Clwyd River Authority  
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 \*Mersey and Weaver River Authority  
 Central Flintshire Water Board  
 \*Chester Waterworks Company  
 Liverpool Corporation Water Works  
 \*Mid Cheshire Water Board  
 \*Wirral Water Board

\* Only by correspondence and/or telephone

District Valuer, Wrexham  
\*Lytham District Land Registry

Liverpool University  
Biological Station, Neston  
Tidal Institute and Observatory, Birkenhead  
Manchester College of Science and Technology  
Manchester University  
Mr. L. Draper (National Institute of Oceanography)  
Mr. Stanley W. Hill (Arthur Collins & Co.)  
Dr. J. W. Jones (Liverpool University)  
Mr. F. T. K. Pentelow (the late)  
Captain G. A. Wright

Laboratorium voor Grondmechanica, Delft  
Rijkswaterstaat Deltadienst  
Waterloopkundig Laboratorium, Delft

Admiralty Chart Establishment  
Dee Estuary (Wirral) Joint Committee  
Lancashire and Merseyside Industrial Development Association  
Lancashire and Western Sea Fisheries Joint Committee  
Mersey Docks and Harbour Board  
Merseyside Area Land use/Transportation Study (Mr. B. Helm)  
National Trust  
Ordnance Survey  
\*Trinity House  
Welsh Tourist and Holiday Association

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Standard Telephones and Cables Ltd.  
J. Summers and Sons Ltd., Shotton  
Synthite Ltd.  
Tunnel Portland Cement Co., Padeswood  
Westminster Dredging Co. Ltd.  
G. Wimpey and Co. Ltd.

GEOLOGY1. Geological sequence

RECENT (POST GLACIAL)	estuarine alluvium, blown sands, coastal submerged peats and clays
GLACIAL	Boulder Clay, silts } partly sands and gravels } contemporaneous
TRIASSIC	Bunter Sandstone and Pebble Beds
CARBONIFEROUS	Coal Measures { Gwespyr Sandstone Millstone Grit { Holywell Shales { Cefn-y-Fedw { Sandstone Carboniferous Limestone

2 General geology

(a) The superficial deposits underlying the Dee estuary have a "valley in valley" form, as the recent deposits of sand and mud occupy a trough eroded in glacial deposits which in turn, lie in a wider deeper valley cut in Triassic and Carboniferous rocks.

(b) The general depth of the pre-glacial valley of the Dee lies between 30 feet and 100 feet below O.D. across the width of the estuary. A narrow channel, almost 300 feet deep at the head of the estuary, is believed to follow the Flintshire side. Howell <sup>96</sup> who is studying the bedrock surface of north-west England suggests the presence of a subsidiary buried channel, also narrow in width, on the Wirral side of the estuary. The results of boreholes 6 and 51 of the site investigation reported in appendix B4 have some bearing on these theories.

(c) Gresswell <sup>95</sup> postulated that the Dee estuary, together with the mid-Wirral depression and the Mersey estuary, represent glacial iceways through which the Irish Sea ice penetrated into the Cheshire basin. His conclusions were based upon observations of the geomorphology on the landward side.

3. Solid geologyGeneral

(a) Carboniferous strata extend around the Dee estuary from Point of Air via Flint to Neston while the remaining section to West Kirby is formed of Triassic strata. The two formations are separated by a boundary fault with a throw which is thought to be from 2,000 to 3,500 feet. The fault can be traced for 2 miles along the Wirral coast from Neston southwards.

(b) The Carboniferous strata have an easterly dip and plunge beneath the younger Triassic rocks that occupy the synclinal tract of the Wirral.

(c) Carboniferous strata are present under the estuary itself as evidenced by the coal workings extending out from Holywell and Neston. However, borings made by the National Coal Board indicate a down-thrown area of Triassic rocks within the Carboniferous rocks under the estuary.

Carboniferous

(d) Exposures of Carboniferous strata are confined mainly to high ground on the Flintshire side but elsewhere they are masked by alluvial and glacial deposits.

(i) Carboniferous Limestone

The Carboniferous Limestone forms a prominent ridge parallel to the estuary and is well exposed in the area from Holywell to Halkyn Mountain. It consists of over 1,000 feet of hard, white and grey limestone generally pure but sandy in places.

(ii) Cefn-y-Fedw Sandstone

The Cefn-y-Fedw Sandstone outcrops around Llanasa and near Holywell. The outcrops are described in the Regional Guide to North Wales as "dominantly a series of grits, conglomerates, sandstones and quartzites, originally more or less calcareous, but now decalcified".

(iii) Holywell Shales

The Holywell Shales consist of up to 600 feet of rather soft blue-black shales and mudstones with some sandstones, outcropping to the south-west of the Gwespyr Sandstone.

(iv) Gwespyr Sandstone

The Gwespyr Sandstone is a fine-grained, micaceous, laminated sandstone which, with the Coal Measures, shows synclinal folding broken by faults on a line parallel and adjacent to the Flintshire side of the estuary.

(v) Coal Measures

The Coal Measures consist of a variable series of clays, shales, mudstones, sandstones and coal seams.

Triassic

(e) The Triassic strata are masked by Boulder Clay deposits. However red Bunter sandstones, may be seen in many places inland, both as natural exposures and in cuttings. They are fine to medium sandstones varying in coherence from a firm stone to a rather soft sand. Locally, beds of hard coarse sandstone are developed, e.g. at Thurston Hill. Bunter pebble beds are exposed at Hilbre Point and from Hilbre Island to Tanskey Rocks. They are compact, coarse-grained sandstone, with rounded pebbles scattered throughout.

4. Drift deposits

(a) The glacial deposits of the Dee estuary are known as "Northern Drift" and were deposited by the Irish Sea ice that swept south-eastwards. The dominant member is Boulder Clay which was found in some boreholes; but is more easily examined in the cliffs, mostly over 50 feet high, that extend for about three miles from West Kirby to Heswall. The slopes of the cliffs are surprisingly steep in many places, 60° to 70° being quite common but elsewhere the slopes are as low as 30° to 40°.

(b) The Boulder Clay is a stiff reddish to brown sandy, silty clay and the proportions of the sand and silt fractions vary widely; from its colour the clay seems to derive mainly from local Triassic deposits. Scattered erratics, mainly cobbles and small boulders occur throughout the clay. The largest boulder visible in the cliff section was about 3 cu. ft. The erratics include Palaeozoic sandstones and mudstones, Carboniferous sandstones and limestones, red Triassic sandstones and various igneous rocks.

(c) Sporadic lenses of gravel occur within the Boulder Clay. These consist of rounded fine to coarse gravel, with a few cobbles, set in a variable matrix, mainly of sand, but containing admixtures of silt and clay. The lenses seen along the coast were twenty to thirty feet in

lateral extent and mostly no thicker than 12 in. to 18 in.

(d) Previous borehole records indicate that the thickness of the glacial deposits preserved in and around the periphery of the Dee estuary ranges from 10 to 60 feet.

(e) Boulder clay was found at depths between 50 and 90 feet near the Greenfield - Gayton line and at 95 feet at Point of Air, when 3 ft was found overlying the Coal Measures.

#### Alluvium and Peat

(f) At the close of the Glacial period the sea inundated the valley and began the process of siltation which is still continuing.

(g) On the northern shore of the Wirral and along the Rhyl/Prestatyn coastal strip the earliest post-Glacial deposits are forest beds or peats and associated clays, which are now submerged. Two organic horizons are generally present and their thickness ranges from 1 to 3 feet. These were not detected during the present site investigation, but they may occur buried below alluvium near the mouth of the estuary.

(h) Most of the recent alluvium consists of estuarine silty sand which overlies partly eroded Boulder Clay. It is a silty fine to medium grained sand shelly in places and containing seams of gravel. Towards the head of the estuary the upper part of this deposit consists of up to a foot of highly organic black mud.

(i) The origin of the alluvium is partly from the Dee river and partly from shore and seabed sand carried into the estuary by tides. Its thickness ranges from nothing at the shore line to about 100 feet.

(k) Wind blown sand has formed dunes along the coast near the mouth of the estuary which form spits and bars that act as protective barriers against the sea.

SITE INVESTIGATIONS1. Scops

(a) The purpose of the site investigation carried out by Messrs. Soil Mechanics Ltd.<sup>97</sup> was to explore the post-glacial deposits and prove glacial deposits or bedrock. Eight boreholes were put down by shell and auger methods, six of these were on the Greenfield - Gayton line, one at Point of Air and one at White Sands off Flint.

(b) Two wash borings were put down on the Greenfield - Gayton line and one at Hilbre. Static cone penetration tests were carried out at twelve locations, five being at Hilbre, four on the Greenfield - Gayton line, with two upstream and one down-stream of this line.

(c) Surface samples were taken from the saltmarsh and sand-dunes.

(d) The positions of the holes and penetration tests are shown on drawing 15.

2. Sampling

(a) Disturbed and undisturbed samples of the strata were taken at regular intervals from the shell and auger holes. A few disturbed samples and one undisturbed sample were taken from the wash borings. Undisturbed samples were also taken near the surface by driving a sampler by hand.

(b) In cohesive soils open drive undisturbed samples were taken and in cohesionless soils undisturbed samples were taken by a compressed air sampler. A piston sampler was also used for soft cohesive soils and fine-grained cohesionless soil. Undisturbed samples could not be taken in strata where gravel was present.

(c) Disturbed surface samples of dune sand were obtained.

3. Field tests

(a) Standard penetration tests were carried out in cohesionless soil in boreholes using a split spoon sampler.

(b) Static cone penetration tests were performed using 2 ton and 10 ton Dutch deep sounding apparatus.

(c) Field permeability tests were carried out in boreholes. Rising and falling head tests were done by observing the level of water in a standpipe connected to a piezometer sealed into the bottom of the hole.

(d) Two trials were carried out to assess the value of seismic methods in this location.

#### 4. Laboratory testing

(a) The disturbed and undisturbed samples were tested in a soils laboratory.

(b) Density, permeability and mechanical analysis tests were carried out on undisturbed samples of sand and mechanical analysis tests on disturbed samples of gravel and sand.

(c) Classification, undrained triaxial and oedometer consolidation tests were carried out on samples of clay.

#### 5. Succession of strata investigated

##### General

(a) The deposits explored or proved may be divided into three types: bedrock, glacial deposits and estuarine deposits.

(b) Simplified sections through the boreholes together with a graphical representation of typical test results are shown on drawing 16.

##### Greenfield - Gayton

(c) Bedrock. Bunter sandstone was identified at a depth of 60 feet in borehole 51 (2,000 ft from the Gayton Shore).

(d) Glacial deposits. Boulder clay with associated lenses of sands and gravels was encountered at depths between -35 ft and -80 ft O.D.

Up to 15 feet thickness of this material was proved. In borehole 52 a clay similar to the boulder clay in the other holes was found but without any gravel sized particles. In borehole 1 a layer of lacustrine clay 8 feet thick was found at ~55 ft. O.D.,

(e) Estuarine deposits. These consist of silty sands 45 to 75 feet thick becoming gravelly with depth. In borehole 2A an 8 feet thick layer of clayey silt and sand overlaid the sand and a layer of silt 8 feet thick was found above the glacial deposits.

Point of Air

(f) Bedrock. Siltstone identified as Carboniferous strata was found at a depth of ~80 ft O.D.,

(g) Glacial deposits. A 3 feet thick layer of boulder clay was found above the bedrock.

(h) Estuarine deposit. These consist of a depth of sand 73 feet thick with gravel and shells locally and occasional thin silt and clay layers. This was overlaid with a 12 feet thick layer of gravel and in turn by deposits of soft to firm clay and loose sand 4 feet thick.

Flint

(i) Bedrock. Sandstone was found at a depth of ~45 ft O.D.,

(k) Glacial deposits. None were identified.

(l) Estuarine deposits. 39 feet of sand with gravel and shells locally was found, underlying 27 feet of made ground of sand with ash and slag.

Hilbre

(m) Wash-hole PH. 20 at this site proved firm to hard clay at a depth of 29 feet with sand containing thin bands of soft silty clay from this depth to ground level.

6. Properties of Strata

Bedrock

(a) The red-brown medium-grained sandstone in borehole 51 was soft in the upper weathered part but medium hard at the depth of 3 feet 8 inches penetrated. It was medium hard in borehole 6.

(b) The grey siltstone in borehole 4 was fissile and hard.

Glacial deposits

(c) The boulder clay is typically stiff to hard, silty and brown with scattered fine to medium sized particles of gravel. The undrained shear strength varies between 3,000 and 12,000 lb/sq.ft. except for a softened layer at the interface between the boulder clay and the estuarine deposits. The minimum strength found in this layer was 500 lb/sq.ft. The liquid limit varies between 30% and 50% and the plasticity index between 16% and 24%. The clay fraction varies between 13 and 56%. The clay has fairly low compressibility, the coefficient of volume compressibility being between 0.003 and 0.007 sq.ft./ton. The coefficient of consolidation varies between 10 and 240 sq.ft./year.

(d) The glacial sands and gravels are dense to very dense, standard penetration tests giving results of 90 to 120 blows.

(e) The layer of lacustrine clay in borehole 1 is a laminated red-brown soft to firm clay with fine to medium sub-angular and rounded gravel. Undisturbed samples of this material could not be taken for testing.

Estuarine deposits

(f) Sands These are mainly silty fine to medium brown and grey sands with traces of shells and with fine to medium gravel in the deeper horizons. Thin bands of silt and clay are present. Typical grading curves of the fine to medium sand and the gravelly sand at the lower depths are shown on drawing 16. There is a large variation in the density of the sand ranging from a loose to a very dense condition. There is no evidence pointing to an increase of density with depth or of correlation of densities between adjacent boreholes. Standard penetration tests give blow counts ranging between 10 and 80 while the in-situ dry density varies between 90 and 106 lb/cu.ft.

This is reflected in the relative density which ranges between 16% and 67% and the porosity between 45% and 35%.

(g) The permeability of the sands as measured on undisturbed samples in the laboratory is about  $10^{-3}$  cm/sec. The field permeability tests gave results of about  $10^{-4}$  cm/sec. The field tests were difficult to carry out and the reliability of the results is in doubt.

(h) The static cone penetration tests carried out on or near the Greenfield - Gayton line show an increase of resistance with depth, indicating that apart from the surface deposits the sand is compact. However, except for two tests the soundings did not go below a depth of 20 feet. In the two deeper tests there is some falling off in resistance.

(j) At Hilbre there is a marked reduction in cone resistances below about 10 to 15 feet and some of the sand down to a depth of 25 feet is in a loose state.

(k) Silt The silt at the base of the estuarine deposits in borehole 2A is described as a red-brown fine silt becoming a soft clayey silt. The undrained shear strength of a sample tested in the laboratory was 2,750 lb/sq. ft. but this may be unrepresentative. The compressibility is low, the coefficient of volume compressibility being 0.001 sq. ft./ton. The coefficient of consolidation varies between 100 and 200 sq. ft./year.

(l) A test on the silty material at the surface in borehole 2 indicates that its permeability may be lower than that of the underlying sands.

(m) Clay The clay near the ground surface in borehole 4 is a soft grey-brown clay with a little sand and silt. The dry density of an undisturbed sample is 60 lb/cu. ft.

## 7. Seismic trials

The two seismic trials indicate that this method may be useful for finding the interface between the estuarine and glacial deposits. However, the accuracy when compared with borehole information was not high.

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MAIN ASSUMPTIONS AND LIMITATIONS  
OF PHASE I STUDY

The results of the Phase I study should be considered in the light of the various assumptions and limitations outlined or referred to below:-

- (a) Time horizons. Most planning and projections are currently taken to 1981 but, for a staged scheme not starting to yield benefits before the mid-1970s, 2001 is a more suitable horizon. For present purposes and to be conservative, transport benefits have been stopped at 2001, also partly because the national transport pattern by then may be radically changing. Water costs and benefits, on the other hand, have both been extended in perpetuity for consistency with staged development; this approach approximates to taking a life of 60 years from 1976 - appendix E9.
- (b) Population. The first page of appendix E1 gives the derivation of population assumptions for Great Britain of 61.8 million in 1981 and 73 million in 2001.
- (c) Urban and industrial development. Benefits were not measurable - chapter 4.7 and appendix E2 (b).
- (d) Communications. Assumptions for traffic predictions are contained in appendices C1 to C3; limitations are summarized in appendix C5. A constant "1981 road network" is assumed - 2.2.1, 2.2.2 (x) and appendix E3 last paragraph.
- (e) Any third highway crossing of the Mersey in the conurbation is assumed to be located between Port Sunlight and Bromborough - 2.2.2 (q); the resulting further benefits of about 10% to a Dee crossing are excluded on the assumption that a third Mersey crossing would be built afterwards.
- (f) Traffic benefits are calculated for diverted traffic at 5.6d. per mile saved and 252d. per hour saved (1966 prices - derived by price index adjustments to figures of 5d. and 196d. respectively at 1962 prices) - appendix E3, stage 2; benefits to generated traffic are measured at half the difference between journey costs by the existing route and by the new route - appendix E3, stage 4.

(g) Pending hydraulic model tests, no firm assumptions could be made about navigation - 1.4 (b) (xi), 2.2.5.

(h) Water. Annual rates of demand increase for Dee estuary scheme supplies starting in 1976 are assumed to be 10 mgd/year to serve some area with a (1966) population of 6 million or 5 mgd/year to serve a (1966) population of 3 million, the latter corresponding to the present Dee supply area and Flintshire - appendix D2. Dee estuary water is valued at an assumed cost of supplying the area from alternative sources, giving a valuation of benefits at about one-third more than the costs - appendices E5 and E9.

(j) Amenities nature conservation and recreational facilities. In general these are not valued; it is assumed that uncontrolled accretion of sand and silt in the estuary would be unacceptable.

(k) Land. Land is valued at current agricultural prices - appendix E6 (m). No assumptions could be made about demand for land for specific uses.

(l) Fish. It is assumed that the numbers and timing of salmon runs would be adversely affected by estuary works unless positive counter-measures were taken - 2.6.1 (k).

(m) Any new trout and coarse fisheries are not valued.

(n) Other economic factors. A discount rate of 8% is assumed throughout - 4.6 (b). Constant (1966) prices are used throughout - 4.4(d). Distributional aspects are not considered in Phase I - 4.7 (iv), appendix E6 (n).

(o) Engineering. A conservative approach has been used in preliminary design and costing procedures for dredging and other marine works, especially in half-tide working in an unstable estuary; heights, closures and protection of embankments have merited special study because of their potential significance in costs - chapter 5.1.

(p) Site investigations and surveys in Phase I have been limited and any assumptions deduced have been conservative. In particular, it has

been assumed that some of the estuary sands would need stabilizing by blasting in order to take embankment loads - section 5.1.1 (c).

(g) For seepage calculations, permeability of estuarine sands has been taken as  $10^{-3}$  cm/sec. - 5.1.1 (e), appendix B4, 6 (g).

REQUIREMENTS FOR PHASE II

1. Depending upon the decisions taken (chapter 1.5), the following requirements for Phase II are suggested :-

- \*+ (i) continue hydraulic model tests; interim report on navigation;
  - \* (ii) full scale O.D. traffic survey and study (appendix C5) and economic evaluation;
  - \* (iii) detailed approach road surveys;
  - \*+ (iv) further site investigations; detailed investigations for materials; full geological report;
  - \* (v) refine multi-purpose schemes as required and, in the light of model test and investigation results becoming available, reduce to only a few schemes; preliminary design; detailed estimates and economic study; interim report to enable choice to be made and limits of all highway and other works (especially outside the estuary tidal limits) to be delineated for parliamentary plans;
  - \*+ (vi) install more river gauging stations and pursue hydrological studies; detailed checks on drainage, floods and flooding aspects;
  - \*+ (vii) widen water supply study slightly after receipt of information from Water Resources Board; refine the economic study on water;
  - \* (viii) further land use studies as required;
  - \* (ix) amenity and landscaping studies;
  - \*+ (x) form advisory group on recreational uses and continue studies;
  - \*+ (xi) wider economic study related to alternative strategies for regional development, proceeding if necessary by ad hoc individual studies (e.g. on industry, including tourist industry aspects) leading to interim reports; study of distributional aspects of scheme as required;
  - \*+ (xii) institute research programme on salmon and sea trout fishery;
- \* essential for obtaining powers  
 + continuing concurrently with obtaining powers.

- \*+ (xiii) develop proposed scheme to the extent required to obtain powers for construction;
- + (xiv) detailed studies of sewage works' effluents, trade wastes; water quality and treatment investigations, with pilot tests;
- + (xv) hydraulic model tests on closure, bank protection, spillways and fish passes, as needed;
- + (xvi) new air surveys;
- + (xvii) large scale tests on: building embankments; leakage from estuary reservoirs; biology of reservoirs;
- + (xviii) study toll crossing implications further, only if needed;
- + (xix) liaison with National Coal Board and C. E. G. B.

2. Phase II could be sub-divided into Phase II(a) comprising enough work on the above to enable a decision to be taken to advance a specific scheme for obtaining Parliamentary powers; Phase II(b) would be a continuation of the work up to the time of depositing a Bill; Phase II(c) would be a continuation up to the time when a decision could be taken to proceed with detailed design and preparation of tender documents. The approximate costs, excluding the costs of large scale tests, would be :-

Phase II(a)	£250, 000
Phase II(b)	100, 000
Phase II(c)	<u>50, 000</u>
	£400, 000

Costs of large scale tests cannot be predicted before the permissible scope for them has been discussed during consideration of the report. Expenditure committed on the present hydraulic model is not included but £75, 000 is included (and divided pro-rata to total costs) for further tests listed in part V of appendix B1.

3. Possible timings are indicated on drawing 18.

- \* essential for obtaining powers
- + continuing concurrently with obtaining powers

TRAFFIC FORECASTING MODEL

(a) There are several independent methods of forecasting travel patterns between zones, each with definite advantages and disadvantages for particular situations.

(b) The Growth Factor method projects the present travel pattern forward on the basis of expected growth of traffic for different zones. Significant changes in transportation facilities or the establishment of new areas of population cannot therefore be predicted.

(c) The Intervening Opportunities model is based on the premise that total travel time from a point is minimized subject to the condition that every destination point has a stated probability of being accepted if it is considered. Absolute distance is treated as of lesser importance than the availability of opportunities to fulfil the travel desires.

(d) The Gravity Model assumes that the number of journeys between two zones is directly proportional to the relative attraction of each zone and inversely proportional to some function of their spatial separation. It is the model most widely used to date, is simple in concept and has been well documented.

(e) A simplified gravity model best suited Phase I of this study since few data were required and these were obtained from other sources without further field studies.

(f) The general form of the gravity model is as follows :-

$$T_{ij} = \frac{P_i \cdot A_j \cdot F_{ij} \cdot K_{ij}}{\sum (A_j \cdot F_{ij} \cdot K_{ij})}$$

where  $T_{ij}$  = trips produced in zone i and attracted to zone j.

$P_i$  = trips produced by zone i.

$A_j$  = trips attracted by zone j.

$F_{ij}$  = empirically derived travel time factor expressing the average area-wide effect of spatial separation on trip interchange between zones which are  $t_{ij}$  apart. This factor approximates to  $1/t^n$  where n varies according to the value of t, and t is the travel time between zones.

$K_{ij}$  = specific zone to zone adjustment to allow for the effect on travel patterns of defined social or economic linkages not otherwise accounted for in the gravity model formulation.

(g) In Phase I it has been assumed that the number of trips generated and attracted by a zone is proportional to the population of that zone and that the factor  $K_{ij}$  is constant for all zones; these assumptions having been necessary in the absence of a field survey. The model accordingly becomes :-

$$T_{ij} = \frac{K \cdot (\text{Pop}'n)_i \cdot (\text{Pop}'n)_j}{t_{ij}^n}$$

where K is now a proportional constant.

(h) An over-all value of 2.44 for the index 'n' was found in a study of travel between five urban areas in Michigan in America, spatial separation being measured in terms of distance in that instance. Where no basic information on the index is available a value of 2.00 is often used but American studies have suggested that a value as high as 3.00 could be correct in some cases. It was therefore felt that without full survey correlation a value of 2.44 would suffice. Use of such a precise figure is not intended to imply a high degree of accuracy.

DATA AND CALIBRATION FOR GRAVITY MODELHighway network

(a) Before the gravity model can be used to predict the future zone to zone flows, it must first be established that existing flows can be determined satisfactorily. A network was therefore constructed of all primary traffic routes near the Dee estuary and this coarsened as the distance from the estuary increased, until only one route was used from the South East to the South West of England. Similarly, the zone sizes increased with distance from the Dee until the whole of Scotland was contained within one zone.

(b) Each link in the network was assigned a speed appropriate to that obtainable on the road or roads it represented. From these speeds the journey time on each link was computed.

Population values

(c) For the purposes of the gravity model calibration, population estimates of the Registrar General for 1962 have been used, with appropriate factors to allow for the likely variation in trips produced by large compared with small urban areas.

(d) Various authorities have suggested that more trips per household or per car are produced by small than by large conurbations.

Ref:- London Traffic Survey, Vol.1, p.3 of "A Brief Account of the Survey" centre column, para.2:

"The distance of a household from the centre affects car-owning and non-car owning households differently. Car-owning households within two miles of Charing Cross make about five journeys a day and this rate increases steadily to over seven journeys at fourteen miles radius, beyond which it remains constant ..."

Ref:- Highway Research Board Bulletin 253, p.131, para.3:

"Generally, there are about four and a half trips per car in the largest cities, five trips per car in cities between 250,000 and 500,000 and around six trips per car in cities of less than 100,000..."

(e) Factors ranging from 1.00 for zone populations greater than 5,000 to 1.33 for zone populations less than 100,000 were applied to the populations to allow for these variations.

### Car Ownership

(f) Implicit within the value of the K factor of the gravity model formula is some recognition of the 1962 level of car ownership. Using national figures obtained from Road Research Laboratory estimates between 1962 and 1981 the level is expected to rise from 0.212 to 0.456 cars per head. A corresponding value of 0.531 cars per head is expected in 2001.

(g) The levels for Merseyside are slightly lower than the national figures but the rate of increase is about the same.

(h) Within the London Traffic Survey, values for increases in car ownership are given together with the increases in trip generation expected. These trips are then segregated into those likely to be by car.

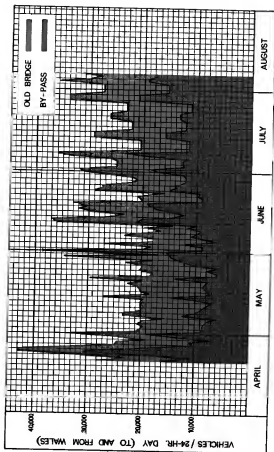
(i) For Phase I it is assumed that most trips within the Dee area will continue to be by private transport and that public transport remains at the present levels. The London trip generation figures and national car ownership figures have therefore been applied to the Dee traffic flows.

(k) The resultant increases in trips over the 1962 level, per head of population, are thus 43% in 1981 and 60% in 2001.

### Calibration

(l) The number of trips generated by the zones was then calculated from the simplified formula with a unit value of K. These trips were assigned to the highway network by the shortest time route.

(m) In the first week of August 1962 a count of traffic on the two crossings at Queensferry had shown an average flow of 28,500 vehicles per 24-hour day, ranging from 26,000 - 31,000. To convert this flow to a 16-hour flow, a factor 92.2% was used (ref. Research on Road Traffic HMSO p.43). A 16-hour flow of 25,000 vehicles was taken as a reasonable value for calibration purposes. Seasonal variations are shown in figure A.



1962 CROSS-DEE TRAFFIC COUNT AT QUEENSFERRY

(n) Correlation between the assigned flow at Queensferry and the 1962 flow was obtained by adjusting the factor K. Corresponding flows were checked for other links in the Wirral and North Wales near the estuary. Where the assigned flows differed substantially from 1962 traffic counts, the speeds on those links were revised and this process of 'calibration' was repeated until the network showed an accurate picture of existing traffic conditions. At the Mersey tunnel it was known that demand exceeded capacity and the flows within the model recognised the excess demand.

#### Holiday traffic

(o) Since the calibration was against August 1962 traffic counts, it was clear that some traffic would be generated solely by the holiday centres in North Wales and thus be unrelated to the static population. A small network was therefore set up for these zones and the total number of beds available for holiday accommodation was taken to be the measure of production and attraction of trips. It was clear that these flows were enough to remedy the apparent shortfall of the gravity model flows in the North Wales area.

#### Toll Crossing

(p) In order to gauge the effect of a toll on vehicles using the crossing, a toll of 2/6d per vehicle was adopted arbitrarily, for the case of a crossing in the middle zone of the estuary. An equivalent time penalty for routes including the crossing was inserted in the traffic gravity model for 1981, and the consequent traffic flows computed again (see table 2, appendix C4).

CALCULATION OF TRAFFIC RESULTS

(a) In addition to the condition with no estuary crossing, five crossing conditions were investigated as follows :-

1. Outer zone crossing (route QP);
2. Middle zone crossing (route HNJC);
3. Inner zone crossing (route AFB);
4. Middle zone crossing (route HNJC) together with inner zone crossing (route FB) and including the proposed coastal link (route NUDF);
5. Combined middle zone inner zone crossing (routes HNUDEB and EG).

(b) The traffic present under the condition with no estuary crossing may be called 'divertable traffic' since this is the traffic for which savings in time and distance are measured on each of the other networks. In addition to this 'divertable traffic' there will be, on each other network, some traffic which would not exist without an estuary crossing. This is the 'generated traffic'. The savings for 'divertable traffic' are measured in terms of vehicle miles and vehicle hours for each crossing position.

Mersey crossings

(c) It was apparent that by 1981 the flows across the three Mersey crossing links were much higher than their capacities. The only certain way to introduce the effect of this overloading or indeed of any other overloading would have been to use the principle of capacity restraint. This, however, is an iterative process which assesses at any stage of the assignment the likely running speed of any additional traffic and, to avoid overmuch use of the computer in Phase I, an approximate correction was applied.

(d) The destination of traffic using either the estuary crossing or the Queensferry link was found for each assignment by the 'Selected Link Assignment' method. This showed the volume of this traffic using the Mersey crossings. From the main assignment the overloading of these crossings was also known. Hence the reduction of these flows was calculated, assuming uniform restraint for all pairs of origins.

For a typical correction

- let             $A$  = total demand at Mersey crossings  
               $B$  = total capacity at Mersey crossings  
               $C$  = total demand at Dee estuary crossing  
and             $D$  = cross Dee estuary/cross Mersey demand

Then the corrected flow

$$E = C - D (1 - B/A) \text{ for } A > B.$$

(e) The benefit to diverted traffic due to the provision of a Dee crossing is proportional to the differences in vehicle miles and vehicle hours on the two networks. It has been assumed that the reduction in benefit occasioned by a restraint at the Mersey is proportional to the reduction of flow at the Dee.

Let  $F$  = total saving, in vehicle miles or vehicle hours.

Then the corrected saving  $G = F \times E/C$ .

(f) This correction assumes that none of the restrained traffic diverts to any other Mersey crossing. Any generation caused by the provision of a new Mersey crossing near Runcorn would already be generated on the Runcorn Viaduct link to sufficient accuracy for flows near the Dee estuary.

#### Accidents

(g) In Phase I it has been assumed that the number of accidents would remain constant with or without an estuary crossing. The lower accident rate brought about by improving the road system with a crossing would be offset, more or less, by the increase in total vehicle - miles travelled due to the incidence of generated traffic.

#### Benefits

(h) Benefits to traffic on existing roads have not been assessed, since the simplified approach adopted for the Phase I Study has not included any effect of congestion. Nevertheless it is of note that relief of congestion on the existing roads may not be of great value to the existing traffic since more traffic would be generated by this relief.

(j) In calculating annual savings in vehicle hours and vehicle miles (tables 1 to 4, appendix C4), the estimated traffic flows per 16-hour day in August have been converted to 24-hour flows by dividing by the factor 0.922, and then multiplied by a factor  $0.833 \times 365$  for annual values compared with August daily values.

(k) The calculations of financial benefits from road crossings to diverted and generated traffic appear in appendices E3 and E9.

Table 1 - Traffic flows and annual savings for 1962  
(Vehicles per 16 hour day, two-way)

Location of estuary crossing	Third Mersey crossing	Traffic on estuary crossing			Traffic at			Annual diverted savings	
		diverted	generated	total	Queensferry	Chester Outer Ring Road	Chester Road (A55)	vehicle miles	vehicle hours
No estuary crossing	with without				27,400 23,600	3,600 3,800	2,400 2,400		
Middle zone crossing	with without	14,850 12,200	4,400 5,400	23,200 18,600	16,400 14,600	5,000 5,000	2,800 2,800	22,921,750 18,764,400	1,664,800 1,364,800
Crossings in middle and inner zone together	with	(a) 12,200 (i) 5,000	4,200 1,500	21,100 6,500	14,200	4,000	2,800	23,120,300	1,835,200
	without	(a) 10,700 (i) 4,800	5,400 1,300	17,100 5,800	12,400	4,000	2,800	18,652,000	1,546,100
Middle zone/inner zone crossing	with without	22,400 17,800	12,500 9,500	34,400 27,400	8,400 8,000	3,200 5,200	2,800 2,800	28,610,600 18,450,400	1,552,300 1,328,800

(a) denotes middle zone

(i) denotes inner zone

Table 2 - Traffic flows and annual savings for 1981  
(Vehicles per 16 hour day, two-way)

APPENDIX C4  
(cont'd)

Location of estuary crossing	Third Mersey crossing	Traffic at estuary crossing			Traffic at			Annual diverted savings	
		diverted	generated	total	Queensferry	Chester Outer Ring Road	Chester Road (A58)	vehicle miles	vehicle hours
No estuary crossing	with without				51,000 46,800	21,800 22,600	5,200 5,200		
Outer zone crossing	with without	20,000 17,600	10,900 2,800	30,900 20,400	28,600 24,000	18,400 15,400	4,800 4,800	451,500 406,100	2,680,300 1,850,600
Inner zone crossing	with without	27,600 25,400	7,800 7,200	45,400 42,700	26,600 24,600	10,000 10,000	4,000 4,000	-11,562,600 -18,924,300	1,175,400 1,110,400
Middle zone crossing	with without	26,800 22,600	14,300 12,200	41,100 38,800	21,600 20,200	11,000 11,000	4,200 4,200	26,485,300 23,383,900	2,671,500 2,354,500
Crossings in middle and inner zones together	with	(a)25,700 (b)10,200	14,900 2,100	37,700 13,700	26,200	6,200	4,800	26,858,900	2,681,500
	without	(a)21,100 (b)10,000	11,900 2,800	33,900 13,900	24,400	8,800	4,800	24,364,900	2,594,500
Middle zone/inner zone crossing	with without	26,000 22,200	25,800 16,100	60,800 52,300	17,600 17,400	11,400 11,400	4,000 4,200	21,689,100 16,064,200	2,456,800 2,130,200

Middle zone crossing with 2/6d toll	with without	11,500 8,000	4,800 4,000	16,400 13,900	25,200 22,300	21,800 21,800	5,200 5,200	16,656,900 26,686,200	1,837,100 1,459,300
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(a) denotes middle zone

(b) denotes inner zone

Table 3 - Traffic flows and annual savings for 2001  
(Vehicles per 16 hour day, two-way)

Location of estuary crossing	Third Mersey crossing	Traffic on estuary crossing			Traffic at			Annual diverted savings	
		diverted	generated	total	Queensferry	Chester Outer Ring Road	Chester Road (A55)	vehicle miles	vehicle hours
No estuary crossing	with without				20,300 16,000	25,400 26,400	8,600 8,600		
Middle zone crossing	with without	40,400 87,000	22,200 18,600	62,600 50,800	61,400 49,200	18,000 18,000	7,800 7,800	27,258,400 33,686,800	4,237,900 3,253,600
Crossings in middle and inner zones together	with without	(m)36,500 (i)17,200 (m)33,400 (i)16,500	20,800 5,800 18,400 8,100	57,300 23,000 51,800 21,600	42,200 34,200 40,200	14,200 14,200	7,800 7,800	43,280,400 46,284,100	4,568,100 4,538,400
Middle zone/inner zone crossing	with without	66,600 58,500	34,000 31,200	82,600 84,700	80,200 29,800	18,200 18,200	7,800 7,800	24,166,300 30,667,700	3,673,300 3,588,200

Table 4 - Traffic flows and annual savings for 2001 with 200,000 additional population in North Wales  
(Vehicles per 16 hour day, two-way)

Location of estuary crossing	Third Mersey crossing	Traffic on estuary crossing			Traffic at			Annual diverted savings	
		diverted	generated	total	Queensferry	Chester Outer Ring Road	Chester Road (A55)	vehicle miles	vehicle hours
No estuary crossing	with without				126,400 127,800	25,400 25,400	18,200 18,200		
Middle zone crossing	with without	61,400 55,000	24,800 31,200	86,200 86,000	83,400 85,800	30,200 30,200	13,800 13,800	59,526,000 43,788,000	8,821,400 4,645,400

(m) denotes middle zone  
(i) denotes inner zone

LIMITATIONS OF PHASE I TRAFFIC STUDY  
AND PROPOSALS FOR PHASE II

Simplified gravity model

(a) No attempt has been made in the simplified gravity model study of Phase I to assess independently the number of journeys likely to emanate from each of the zones into which the country as a whole has been divided. The standard gravity model apportions the total number of trip ends between zones according to a gravity technique. Such trip ends could be obtained in practice only by extensive surveys.

(b) The simplified form of the model described in appendix C1 depends upon the function of the spatial separation adopted. It is known that in practice this function depends upon both vehicle classification and trip purpose. For example in the particular study<sup>19</sup> from which the overall value of 2.44 for the index of journey time used in appendix C1 was abstracted, actual values were found to vary from 1.58 for trucks with trailers, to 2.81 for estate cars. In the same study the value of the proportional constant (K) varied from 0.32 to 157.

(c) Not only does the function of spatial separation vary with the vehicle classification and trip purpose but there is evidence that it may vary with the spatial separation itself.<sup>21, 24</sup>

Highway Network

(d) Within the gravity model itself the total number of links in the network had to be limited. The network was therefore planned to consist of all primary roads near the Dee estuary but with single routes further afield, for example between London and Bristol and between London and Edinburgh. These approximations are considered to be insignificant.

Assignment technique

(e) The volume of traffic attracted to any route in practice depends upon the speed attainable on that route, which in turn must vary with the flow on the links comprising the route. An iterative procedure is required in order to obtain balanced flows, whereby on completion of the iteration the volumes of traffic on all links are compatible with the speeds. A drawback of the method used in Phase I is that, in the absence of an iterative technique, a measure of the secondary generation of traffic resulting from reduction in congestion on some routes could not be included.

(f) Traffic has been assigned on a minimum time ("all or nothing") basis. A more realistic measure of spatial separation would be minimum cost. This approach has not been considered appropriate in Phase I but is a refinement to be adopted in Phase II.

Traffic characteristics

(g) Values of trip increases compared with car ownership increases have been assessed by reference to 'The London Traffic Survey' and other studies for the country as a whole. The study area may have its own growth characteristics affecting the estimated trip increases.

(h) In Phase I, hourly flows could be assessed only empirically as a percentage of daily flows.

Travel pattern

(j) Another problem, the solution to which has not been attempted in Phase I, related to possible change in travel habits. The opening or closure of railway lines or the introduction of new forms of transport may occur by 1981 and people now travelling by car may travel by train instead or vice versa. Again, by 2001, restraints on traffic entering city centres could deter would-be road users and force them to change their mode of travel. It has been assumed in Phase I, however that the present pattern of travel will persist at least until the end of the century.

PROPOSALS FOR PHASE II

Traffic studies

(k) The prime need for a traffic study in Phase II would be to predict future traffic flows throughout the region of the Dee estuary more accurately than has been possible in Phase I. This would enable benefit calculations to be refined and highway details and costs of the best crossing scheme to be established. The study would differ from that of Phase I in that it would be based upon a comprehensive field survey of existing traffic movements rather than upon a theoretical prediction of such traffic. In general the techniques used would be refinements of those within Phase I with certain notable exceptions.

(l) The national highway network used in Phase I would be split into an inner region centred on the Dee estuary and an outer region. Within the inner region information would be gathered on the origins and destinations of all traffic, together with details of trip purposes, for different hours of the day. A speed-flow relationship would be established for all roads within this region for use in determining capacities.

(m) Internal trips, that is with origin and destination within the inner region, would be determined by the gravity model as would trips with either origin or destination outside but not both. These two types of trips would be treated separately since different trip length characteristics are expected. Through trips, with neither origin nor destination within the inner region, would be projected by a growth factor method. For all these types of trips an iterative approach would be adopted using the speed-flow relationships previously ascertained.

(n) The total number of trips ending in the inner region would be assessed from data from the field survey and details would be needed of future expansions, not only of populations and car-ownership but also of such production and attraction characteristics as industrial acreage, office space, parking restraints and any new restraints imposed on entry into the main urban areas.

(o) All assignments would be based upon minimum cost rather than upon minimum time, since cost gives a more accurate estimate of deterrence than time alone. The cost would be related to both the time and distance on each route.

HYDROLOGYPresent development

(a) The major authorized or licensed abstractions above Chester weir total some 117 mgd of which 96 mgd will be abstracted at or near Chester. About 15 mgd are returned to the estuary as effluent (see also paragraph (j)). In addition Alwen Reservoir, with a useful storage of 2,600 mg, at present supplies Birkenhead Corporation with 8.35 mgd.

(b) Llyn Celyn and Llyn Tegid (Bala Lake), with a combined useful storage of 16,700 mg, regulate the river to maintain 150 mgd at Erhistock gauging station (drawing 14). Recent calculations indicate that these storages could be used to maintain 170 mgd at Erhistock during a dry period that might occur, on average, once in fifty years; this might allow downstream abstractions to be increased by 20 mgd to 137 mgd.

Mean annual natural run-off

(c) Flows from the upper 401 square miles of the basin have been observed at Erhistock since 1937. The accuracy of the records has not been assessed in Phase I; however all other known estimates of resources in the Dee basin have been based on these records. Monthly flows and catchment rainfalls are tabulated in the Surface Water Yearbooks. The flows, as published, are already partly corrected since 1949 to remove the effects of upstream development and are fully corrected since 1958. The records have been further adjusted between 1937 and 1958 to derive the 'natural' run-off for the complete period of record.

(d) Run-off from the lower 338 square miles of the basin, i.e. excluding the catchments of the river Dee to Erhistock and of the river Alyn to Pont-y-Capel, has been assumed to be similar to that published since 1937 for the river Weaver below Ash Brook (drawing 14). Flows at this station show reasonable correlation with flows recorded at other gauging stations in the area. As the contribution to the run-off from this lower Dee catchment is relatively low, it has been accurate enough to adopt a 'mean' catchment limit in the estuary (drawing 14) for these calculations.

(e) Flows at Pont-y-Capel from the river Alyn catchment of 86 square miles have been measured only since June 1965 and a flow record has therefore been synthesized by comparison with the mean rainfalls over the Erhistock and Weaver catchments as shown in the table. Comparison between these synthetic values and the flows recorded at

MEAN ANNUAL RUN OFF UNDER NATURAL CONDITIONS

Catchment	Area square miles	Mean rainfall				Mean flow 1937-1964 inches	Estimated long term mean flow mgd.
		1881-1915 inches	1916-1950 inches	1881-1950 inches	1937-1964 inches		
River Dee to Erbitstock	401	51.5 <sup>a</sup>	56.9 <sup>a</sup>	54.2	54.2 <sup>a</sup>	36.9 <sup>a</sup>	590
River Alyn to Pont-y-Capel	88		35.7 <sup>b</sup>	34.9 <sup>c</sup>		16.4 <sup>c</sup>	55
Remainder of Dee basin to estuary	338		30.6 <sup>b</sup>	30.1 <sup>c</sup>		11.3 <sup>c</sup>	150
* River Weaver to Ash Brook	(235)	(29.5 <sup>a</sup> )	(30.4 <sup>a</sup> )	(29.9)	(29.9 <sup>a</sup> )	(11.1 <sup>a</sup> )	
Total catchment to estuary	825	41.2 <sup>c</sup>	44.4 <sup>b</sup>	42.8 <sup>c</sup>		24.3 <sup>c</sup>	795

<sup>a</sup> from Surface Water Year Books<sup>b</sup> from isohyets in "Rainfall of the River Board Areas 1916-1950"  
Meteorological Office Hydrological Memorandum No. 13<sup>c</sup> estimated<sup>\*</sup> figures for River Weaver are shown in brackets for comparison  
with the line above

Pont-y-Capel from July to December 1965 shows that the former may have been overestimated by up to 20 mgd. However, the Alyn basin is permeable and, during summer, the whole flow can disappear into swallow holes; it is thought that much of it flows to the estuary through the Milwr tunnel which supplies Courtaulds with 11 mgd. In Phase I the synthetic flows have been assumed to represent the total flow from the Alyn basin reaching the estuary by different routes.

(f) It was found that, for both the Dee at Erhistock and the Weaver below Ash Brook, the mean catchment rainfalls over the period of the flow record (1937 to 1964) equalled the mean catchment rainfalls between 1881 to 1960. Thus mean run-off and loss figures over the period of record were assumed to represent long-term mean conditions. Since the variability of annual rainfall in this area is lower than in most other parts of England and Wales (drawing 14) a period with mean rainfall is more likely to be a period with mean run-off. The estimated mean annual natural run-off figures are shown in the table.

#### Design risk and drought flows

(g) In Phase I the net yield from estuary storages has been defined as the supply that could be maintained throughout a period of low flow likely to occur, on average, once in fifty years (i.e. a 2% chance of occurrence). Later economic studies may show that a higher risk could be taken depending on the location and type of the other resources of water undertakings to be supplied from a Dee estuary scheme. Although after each storage increment is commissioned there would be, in any one year, say, a one in fifty chance that the design yield could not be maintained, storage increments might be brought in at 10 yearly intervals. Thus only in every tenth year might demand reach the design yield and this much reduces the risk of having to restrict supplies at any stage. Moreover reservoir bottom water levels have been chosen so that the estuary flats are not exposed; this gives appreciable bottom storage which could be used to increase the yield or in an emergency to maintain the supply. By the time development is complete, concepts of reservoir operation and of acceptable supply restrictions may well have changed.

(h) A synthetic record of natural, undeveloped inflows to the estuary was derived from the Erhistock and Weaver flow records. 2% droughts of different durations between three and eighteen months were derived from this record by probability analyses. Daily dry period flow values at Erhistock were used to estimate the releases from Llyn Tegid and Llyn Celyn required to satisfy abstractors above Erhistock and to maintain 150 mgd at Erhistock during the design drought. This procedure depends upon the daily flow pattern and must be uncertain.

In Phase II, the effects of many different sequences should be tested. The operation of Alwea reservoir was taken into account and modified inflows to the estuary were produced. It should be noted that most of the 15% operational loss allowed on the upstream regulation releases would reach the estuary storage.

(j) In addition, effluents from the assumed increasing population in the river basin will increase drought flows into the estuary. Some of the basin's resources could therefore be re-used if an estuary water scheme were undertaken. A rise in recirculated effluent from about 15 mgd in the early stages to about 30 mgd at a supply yield of 300 mgd is assumed in this study.

#### Yield of 'gravity' impounding schemes

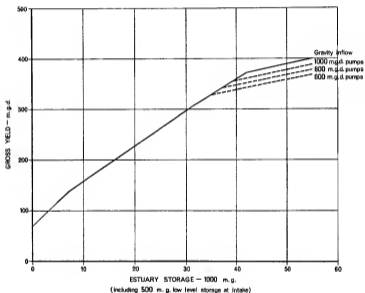
(k) The gross yields from the range of estuary storages under consideration were computed from the 2% drought inflows for periods of different duration. The duration giving the lowest yield for any storage is the 'critical' period for that storage and is the time taken for a full reservoir to reach maximum drawdown.

#### Yield of pumped storage schemes

(l) The yields from gravity reservoirs could be equalled by those from pumped storage reservoirs only if the pump capacities were high enough to match most river flood flows. The use of economic pump capacities however mean that in the latter case slightly more total storage (including balancing) is needed for a given yield, the more so if the critical drought period spans one (or more) winter seasons. To assess this extra storage a realistic daily flow pattern for a 'design' drought was needed and the flow pattern referred to in paragraph (b) was therefore scaled up to represent estuary inflow. Upstream control and authorised abstraction were allowed for before summing the flows above 70 mgd that could be abstracted by different pump capacities in various conditions of storage and yield. Figure B summarizes the gross yields available from pumped storage reservoirs that could be refilled in a few months of normal flow.

#### Compensation flow and unusable effluent

(m) It has been assumed that 70 mgd of fresh water would be released continuously through the fish passes as compensation flow to protect fishing interests.



**YIELD : STORAGE DIAGRAM - 2% RISK OF FAILURE**

(a) Various industries on the Flintshire side of the estuary release polluted effluent which would have to be piped beyond the sluices. If the sluices were downstream of Courtauld's Greenfield works the average quantity would be 11 mgd or if upstream, only 3 mgd but any flow from the river Alyn along the Milwr tunnel (paragraph c) will enter the estuary below the barrage. For simplicity it has been assumed that the total loss for this reason is 15 mgd in either case.

#### Net yields

(c) The following table shows the storages that would be required for yields in 50 mgd increments after allowing for compensation water and losses from seepage under the storage embankments :-

<u>Net yield(mgd)</u>	<u>Low level balancing storage(mg)</u>	<u>High level storage(mg)</u>	<u>Pump capacity(mgd)</u>
100	500	12,000	200
150	500	19,000	300
200	500	27,000	500
250	500	35,000	700
300	500	50,000	1,000

#### Alternative reservoir proposals

(p) More upstream regulating reservoirs built before estuary storage would affect the yield available from the latter. The yield available from any estuary storage must then be determined by moving the origin of figure B to the storage/yield point reached by further regulating reservoirs. This means that the extra yield for each unit increase in estuary storage would be lowered if upstream regulating reservoirs were developed first.

#### Floods

(q) The highest flood flow that has actually been measured at Erbistock, 13,250 cusecs, occurred on 10th December 1965 and reached a gauge reading of 10.4 ft. Higher flood levels have been recorded but changes in the level-discharge relationship over a period of time and the need to extrapolate any relationship observed make it difficult to evaluate all flood flows.

(r) The highest peak level reached in the past 30 years was 12.8 ft on 13th December 1964; the corresponding flow was estimated to be 20,000 cusecs. This is 2.2 times the mean annual flood peak of about 9,000 cusecs. Llyn Celyn was impounding at that time and therefore the Erbstock catchment was effectively reduced by 27 square miles. Cole<sup>103</sup> (1966) in his regional flood analysis suggests that a flood of this size can be expected only about once in a hundred years.

(s) A degree of flood peak alleviation is now afforded by flood protection storage in Llyn Tegid and Llyn Celyn; this can change the timing and level of river flood (and lower) flows and hence modify peak inflows to the estuary.

(t) Peak flows in the Dee at Holt (12.4 miles above Chester) appear to be restricted to about 14,000 cusecs, the balance of the flow going into storage on the meadows below Bangor. A flood balancing basin would be needed in the estuary to guard against the coincidence of a major land flow and a tidal surge. In preliminary design a peak flow of 30,000 cusecs through Chester has been used. This adequately caters for the rare occurrence of a severe flood affecting the whole basin simultaneously.

#### Suspended sediment

(u) The Dee and Clwyd River Authority have collected a few suspended sediment samples at four locations in and near Chester. These data are inadequate to make an accurate assessment of the sediment run-off in the Dee but it is estimated that about 0.2 million tons (equivalent to roughly 40 mg of storage) enter the estuary annually. Preliminary studies suggest that about 25% of this amount, equivalent to 10 mg per year, would enter the bunded storages in the final stages of development. Sediment deposited in the low level storage would probably be flushed through the sluices by natural spates.

#### Recommendations

(v) During Phase II, the hydrological studies should be refined by supplementing the existing records by extra fieldwork and carrying out the further yield and flood studies as outlined below :

## Fieldwork

### (i) River flows

River Dee at Erbstock: The gauging station and flow records from this important station, particularly flood flow records, should be examined in detail.

River Dee at Chester: The level records for Chester weir should be rated over the whole range of flows.

### (ii) Sediment run-off

Comprehensive sediment sampling of both suspended solids and bedload should be taken upstream of Chester weir. This would involve sampling at different points and levels in an observation section, and making both total solids and particle-size analyses to establish the possible loss of estuary storage if siltation were left unchecked.

### (iii) Groundwater

A well water-level survey should be carried out to confirm whether the groundwater catchment (particularly of the river Alyn) is similar to the topographic catchment. This could reveal the origins of the Milwr tunnel water supply.

## Studies

### (i) River flow records

A Chester flow record for past years should be derived from existing level measurements and be correlated with the records for upstream tributary areas to check its accuracy and to assess the various contributions to Dee resources. The extra gauges proposed in the River Authority's hydrometric scheme will reduce the assumptions needed for yield estimates.

### (ii) Regulation by effluent

As the basin population grows and river flow is increasingly modified by effluent, the yield from estuary storage can increase significantly. Present estimates (paragraph j) should be reviewed as development patterns become clearer.

### (iii) Yield studies and reservoir operation

The comprehensive Dee research programme now being undertaken by the Water Resources Board includes the generation of synthetic flows against which to test regulation methods. If convenient to the Board, it would be advantageous to extend these studies to apply to estuary reservoir operation.

(iv) Flood studies

Similarly, the proposed flood routing by analogue techniques could be extended to aid the design of flood balancing storage and sluice outflow characteristics. More detailed studies of the frequency and severity of flooding at and below Chester should be made for both present and future conditions from the further data.

The fieldwork listed should begin as soon as possible as it affects early design decisions. It is expected that the work could be fitted into the River Authority's programme and that the main cost of the studies would be in office and computer time for analysis.

WATER DEMAND

(a) The natural area of supply for water from the Dee has been taken as the area already supplied from this source, that is, most of the Dee and Clwyd River Authority area and the Merseyside conurbation. Allowance is made for future, increased demands from Flintshire, partly stemming from economic growth. An extended area of supply is also allowed for as a possibility\* - see also appendix E5.

(b) Broadly, the range of population covered by these different areas is from 3 to 6 millions in 1966. The following table applies to the higher figure:-

Year	(1) Population millions	(2) Daily consumption per head ghd	(3) = (1) x (2) Demand mgd	(4) Rate of demand increase mgd/year
1962	5.8	51	296	
1966	6.0	55	330	8½
1976	6.6	65	430	10
1981	6.9	70	480	10
2001	8.0	85	680	10
2006			730	10

Population increases are consistent with local projections and with those for England and Wales abstracted from appendix E1. Consumption per head has been assumed to increase at 1 ghd/year until 1981 then at a reduced rate (to allow for an element of saturation) giving a constant future rate of demand increase in column (4). A constant rather than a compound rate

\* At the time of going to press with this report, Water Resources Board Publication No. 4 was issued. It indicates a natural area of supply on Figs. II & VI and an extended area on Fig. V<sub>1</sub> an alternative possibility of export of surpluses to the Midlands is mentioned in paragraph 16.

is conservative and allows for either lower population increases or lower consumptions per head and, coupled with multi-stage schemes, avoids over-investment of capital to meet demands in the remote future. The consumption per head quoted includes for domestic and trade use and for leakage.

(c) A water conservation scheme ultimately yielding 300 mgd, with a first stage available in 1976, would meet demand increases of 10 mgd/year in the extended area until 2006. For the natural area (1966 population of 3 million), the rate of increase would be halved to \*5mgd/year and these demand increases could be satisfied until 2036. It should be noted that estimates of demand increases by present abstractors from the Dee total  $4\frac{1}{2}$  to 5 mgd/year.

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\* See footnote on previous page. Water Resources Board Publication No. 4 indicates differences in deficiencies in possible Dee supply areas of 165 mgd between 1981 and 2001 (say 8 mgd/year) on Figs. II 6 VI or 280 mgd (say 14 mgd/year) on Fig. V.

WATER QUALITY1. River water above Chester weir

(a) Of the total 825 square miles draining to the proposed estuary sluices, 700 square miles represent the catchment down to Chester weir. This area is largely hill country and farm land but (excluding Chester) it contains over 130,000 inhabitants of whom 80% live in or near Wrexham. Most of the sewage is treated at works built or extended in the last ten years to improve the standard of effluent. Other effluents to the river are from steel, chemical, leather, gas and textile works mostly in the Wrexham area and, again, effluent standards have been much improved in the last decade.

(b) Water is abstracted from just above Chester weir by Liverpool Corporation Water Works, Wirral Water Board and Chester Waterworks Company. All supply water for domestic use and have no serious difficulty in treating the raw water. The worst characteristics are taste and odour (which have much improved in recent years) and variable concentrations of ammonia, which have occasionally affected treatment by break-point chlorination.

(c) A table of typical water analyses for the years 1964 to 1966 is given at the end of this appendix.

(d) The water generally has a reaction on the alkaline side of neutral. Its colour, although usually slight, is sometimes pronounced and the highest figure in the table is 125 Hazen; this is probably due in part to peaty colouring matter from the headwaters. Turbidity is usually low and the maximum figure included in the table is 148. The hardness of the water shows quite wide variations between 36 ppm and 147 ppm and the water can be described as "fairly soft" to "moderately hard".

(e) The results for oxygen absorbed and albuminoid nitrogen are consistent with a reasonably clean river water sampled in its lower reaches. The figures for free ammonia are higher than might be expected and sometimes rise to over 1 ppm, not only in the winter when nitrification is retarded by low temperature, but also sometimes in the summer. This is due partly to gas works' effluents which, however, are being improved. The ammoniacal nitrogen content should not persist after reservoir storage.

(f) The figures for nitrate are low, consistent with only a small effect either from fully oxidized sewage effluents or from cultivation on the gathering ground. The chloride figures are quite high, showing the added effects of effluents from chemical factories and possibly from tannery wastes; they should not be taken in this instances as any good indication of the proportion of sewage effluent present. The figures for phosphate and for silica are fairly low.

(g) It has been estimated that the population will rise from 130,000 to 220,000 by 2001. Provided that the domestic sewage, (which might reach 10 mgd) is treated to Royal Commission standard or better, the water quality at Chester weir is not expected to deteriorate appreciably. Trade effluents, of course, must continue to be controlled.

## 2. River water below Chester weir

(a) New sluices 12 miles or more downstream of Chester weir would remove the tidal influence from the canalized reach and upper estuary.

(b) This lower catchment is quite well populated and nearly 9 mgd of domestic sewage effluent from some 210,000 people are also discharged there. About  $4\frac{1}{2}$  mgd of this comes from Chester sewage works which now provides only partial treatment but which is being extended for full treatment by 1969. The balance comes from 10 smaller works on both banks. The quality of discharges tends to worsen towards the seaward end of the estuary but improvement schemes are actively planned for 85% of this balance. New developments are to be mostly on the separate storm water and sewage system and in some cases this will improve the performance of existing installations which are mainly on the combined system.

(c) A detailed examination of sewage treatment works is proposed for Phase II of the study, to check what further measures would be justified to improve the effluents. The implications of the combined systems would be examined, as would the need to achieve a standard of effluent better than that of the Royal Commission. Should a water conservation scheme be implemented, sewage effluents in the future, which might total some 15 mgd by 2001, would have to be controlled carefully to ensure that a high quality was maintained. Allowance has been made in the estimates for some improvements to standards of existing and future effluents.

(d) With a few minor exceptions, trade effluents do not pass through the sewage treatment plants but are discharged separately. Eighteen points of discharge have been recorded. Only one is on the east bank (at John Summers Ltd. steelworks at Shotton) but this discharge is the largest at up to 75 mgd. An equal amount of water is abstracted just upstream but, of this, 65 mgd is cooling water the need for which will soon be greatly reduced after commissioning of a cooling tower; the rate of abstraction and return is then expected to be 25 to 30 mgd. The temperature of the water discharged reaches 10 to 15°F above that at the intake but, with the cooling tower, the rise is expected to be only 5 to 10°F. Analyses of 33 samples of effluent taken over the last seven years show that the quality is variable, no doubt due to intake of water from the tidal reach, affected by different combinations of tide and river flow. The effluent is expected to be suitable for inclusion in the water abstracted but detailed safeguards would require further study in Phase II.

(e) The remaining trade discharges, distributed along the Flintshire bank between Chester and Greenfield, total about 12½ mgd. They include cooling water and effluents from fertilizer, paper and chemical works. In view of the difficulty of treating some of these effluents to a standard suitable for water supply and particularly as the major quantity results from chemical processes, including the manufacture of viscose rayon, an intercepting sewer and estuary outfall have been allowed for. About 11 mgd of the present trade effluents would need to be diverted in schemes Z and ZZ, but only 3 mgd in schemes X, XX or Y with sluices further upstream. The sewer would be generously sized to allow for peak daily flows. Pumps would be required, extra units being commissioned to meet increased effluent quantities in the future. A proposal for a sewer does not imply that the River Authority may not require individual treatment of effluent to some standard before discharge to the estuary (see also paragraphs 2.6.1 (b) (viii) and 2.6.2 (d)).

### 3. Stored water

(a) All schemes proposed for water conservation involve pumping water, retained in the flood balancing basin by the river sluices, to storage in banded reservoirs. The water quality before pumping would correspond with that of river water above Chester weir modified by flows from the lower catchment. Since sewage effluent standards are already being progressively raised and since the present amount involved is only about one tenth of the dry weather flow or one hundredth of the average flow in the river, the modification would not be great.

(b) This water, however, could not be classed with the soft, upland waters stored in reservoirs upstream which have low nutrient salt content. Nevertheless it would be better than water from many

lowland rivers in the south of England and its lower carbonate hardness and other mineral content, including phosphate, should make it no more biologically nutritious than, say, the Thames. \*

(c) Initially some salinity increase from contact with sea water would occur. However with the pumped storage reservoirs proposed this would be minimised. Sea water trapped when the embankments were closed would be let out by gravity at low tide. There would be no net inward seepage of sea water during operation because retention levels would be above mean sea level. Diffusion of salt from the bed of the reservoir would be small because of outward seepage of fresh water. These factors would also apply in the balancing basin but some diffusion from the bed could be expected due to groundwater effects. However due to the high throughput of river water its chloride content is unlikely to be increased by more than 10 ppm (as Cl) at first, falling to 2 ppm after 2 years and less thereafter. Thus if the initial filling of the reservoirs can be carried out in winter when river flows are high and the salinity in the basin correspondingly low the initial chloride content is unlikely to exceed 50 ppm. +

(d) Stratification of the stored water (which aggravates water quality problems) would not be expected due to the limited depth and the effect of wind on the large surface. The latter would aerate the water which would be beneficial.

(e) A typical development programme for the banded reservoirs would allow for two reservoirs to be built initially followed by two or more in later stages. Having several pumped storage reservoirs confers the outstanding benefits of safety and reliability to the water supply source, as well as economies from phased capital expenditure and from treatment costs, compared with those applicable to a single reservoir :-

(i) Since the inflow to each reservoir could be localized and the draw-off point could be well separated from it, a long retention time could be relied upon to improve any bacteriologically inferior water pumped into the reservoir. There would be no danger of short-circuiting the storage.

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\* The Metropolitan Water Board operates large embanked reservoirs some 50 to 60 feet deep and, while prolific growths of algae occur, treatment difficulties are overcome.

+ World Health Organisation International Standards for Drinking Water give 200 ppm maximum acceptable concentration and 600 ppm maximum allowable concentration of chloride.

(ii) Pumping into reservoirs could be selective and be stopped when the river water quality was poor. This feature would be particularly useful in cases of serious pollution of the river by chemical substances e.g. due to accidents in factories or to road tankers.

(iii) Failing other warning, death of fish in the river is normally a good indicator of toxic pollution but, if badly polluted water were pumped inadvertently into one of the reservoirs, the others would still be available for supply.

(iv) With more than one reservoir (each with its own filling and draw-off arrangements), water depths and qualities could be varied. For example, the resulting differences in the timing and extent of any algal blooms in the several reservoirs would enable the best water to be drawn off.

(v) Chemical, hydraulic or biological methods of algal control could be tested and used selectively (and with economy) in the reservoirs ensuring that some water was always available for draw-off (c.f. the risk of finding all the water unusable in a single large reservoir).

(vi) The enclosing banks would give a minimum water depth of about 20 ft. thus avoiding marginal areas of shallow water with the associated problem of aquatic vegetation. With an average depth exceeding 20 ft., algal growths or blooms would signify less because water could usually be drawn from below the zone of most prolific growth (top 10 to 20 ft) from at least one of the reservoirs.

#### 4. Water treatment

(a) In view of the quality of river water which would result from the measures described in section 2 and the provision of a long period of storage with the choice of draw-off from two or more reservoirs outlined in section 3, normal methods of treatment should be adequate.

(b) Treatment could include (i) coagulation followed by sedimentation and rapid gravity sand filtration as already in use by some of the water undertakings using Dee water or, (ii) coagulation, flash mixing and filtration through anthracite and sand rapid gravity filters with or without the use of a polyelectrolyte.

(c) Initial ratings of the filters and of sedimentation tanks (if used) would be conservative but the hydraulic design would be such that ratings could be much increased in the light of pilot plant experience or because of the adoption of new techniques.

(d) The presence of appreciable colour in the raw water, coupled with the known existence of taste and odour which are quite difficult to remove, militate against treatment comprising roughing filters and slow sand filtration, without the use of a coagulant.

(e) Provision for the use of activated carbon or chlorine dioxide for removal of taste and odour, as at present practiced by undertakings using the Dee water, would be essential unless other methods such as ozone treatment become more viable. The possibility of using poly-electrolyte to increase the permissible rating of sedimentation tanks (if used) should also be borne in mind. Microstrainers are unlikely to be required, based on the data at present available.

(f) A characteristic of Dee water worth noting is the somewhat high chloride content and fairly low alkalinity which could result in dezincification of duplex brass fittings so that the use of such fittings should be precluded. Correction of the pH with lime should be effective in limiting normal corrosion.

## TYPICAL RAW WATER ANALYSES

The following data were derived from chemical analyses supplied by Liverpool Corporation Water Works, Wirral Water Board and Chester Waterworks Company for abstractions above Chester weir.

The results are quoted in parts per million unless otherwise stated.

Year	1964			1965			1966		
	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.
Colour (Hazen units)	5	23	50	5	23	70	5	35	125
Turbidity (ppm silica scale)	2	16	62	3	20	110	6	26	143
pH	6.9	7.4	6.3	6.8	7.3	6.1	6.9	7.2	7.6
Electrical conductivity (micromhos/cm at 20°C)	100	285	510	111	250	595	143	270	420
Oxygen absorbed (from permanganate in 4 hours at 27°C)	1.4	3.4	10.0	1.3	3.6	12.6	1.7	3.7	6.8
Free CO <sub>2</sub>	Nil	2.3	6.6	Nil	3.0	5.6	2.0	3.0	6.0
Alkalinity	16	68	117	27	61	100	19	66	97
Permanent hardness (as Ca CO <sub>3</sub> )	13	30	49	10	32	63	15	20	36
Total hardness (as Ca CO <sub>3</sub> )	36	96	166	37	93	147	34	96	143
Nitrogen (as free and saline ammonia)	0.06	0.73	3.29	0.02	0.47	2.12	0.01	0.23	1.22
Nitrogen (as albuminoid ammonia)	0.09	0.38	1.23	0.09	0.34	0.96	0.15	0.32	0.92
Nitrogen (as nitrites)	0.002	0.03	0.12	Nil	0.018	0.10	0.01	0.04	0.15
Nitrogen (as nitrates)	0.2	1.0	2.5	0.2	1.0	2.0	0.2	1.0	2.5
Chloride (as Cl)	11	36	60	12	30	63	13	28	66
Phosphate (as PO <sub>4</sub> )	0.06	0.29	0.56	0.02	0.22	1.64	0.02	0.28	1.24
Silicate (as Si O <sub>2</sub> )	2	5	12	1	6	6	2	6	8
Calcium (as Ca CO <sub>3</sub> )	25	69	116	30	68	110	36	69	101
Iron	0.02	0.21	1.20	Nil	0.32	3.20	0.04	0.61	6.00
Manganese	Nil	Trace	0.21	Nil	0.11	0.61	0.01	0.06	0.32

CLOSURE OPERATIONS

- (a) Professor Matheson reported <sup>112</sup> that the construction of a crossing on the Greenfield - Gayton line should be preceded by the extension of longitudinal training walls to stabilize the river channel in its present course, construction on a line normal to the tidal flow being thought impracticable because of deep scour.
- (b) With modern techniques, however, construction of a closure bank normal to the tidal flow would be feasible and assured, not only on a Greenfield - Gayton or other middle zone line, but also in the outer zone between Point of Air and Hilbre, if so required. Nevertheless, outer zone closures would cost much more than those in the middle or inner zones.
- (c) With staged development of pumped storage in the upper estuary quite small tidal volumes would be involved in the construction of the first reservoirs and little difficulty in closure would be expected. When later stages came to be built the tidal volumes would probably be less than they appear now because of continuing siltation of the estuary.
- (d) Various methods of closure have been used in the past. Many river diversions have been carried out by and tipping embankments from each side using less erodible material (e.g. rock-fill) to close the final gap. The Zuider Zee was closed in a similar way using mainly boulder clay for the final gap. Concrete caissons floated out and sunk on to prepared foundations at the reversal of flow have been used extensively in the Netherlands. In some cases they have incorporated temporary sluices to reduce the water velocity through the remaining gap until all the caissons could be positioned; after closing the sluices, sand-fill embankments have been formed over them. At Harlingvliet tidal sluices are being provided and built first. Closure between the sluices and the shore is to be by rock mound brought up uniformly to form a closure sill. The rock is to be dumped by cableway on to a strip of the sea bed previously protected against scour. This method, first used at Scapa Flow, <sup>133</sup> was used at Grevelingen where there were no tidal sluices. The same method was used to close Plover Cove in Hong Kong but the rock was placed by floating cranes rather than by cableway. A rock mound is the preferred method for use in the Dee estuary, where the average tidal range is 20 ft, due to the difficulty of maintaining a seal beneath caissons in this period after closure and before they have been surrounded by sand-fill.
- (e) The proposed technique for placing the rock-fill is described in chapter 5.1.

SEA DEFENCES1. Criteria for overtopping

(a) Embankment crest levels chosen for defence against sea attack would depend upon the consequences of overtopping and the cost of raising. For a bank carrying a major road or rail link, overtopping would be limited on average to once in 5 or 10 years; some spray would be expected when there was no overtopping. In the case of a minor road more frequent overtopping would be permissible - say once in 3 or 5 years. A much longer return period, say 1,000 years, would be used in design against the risk of a breach and there would be means of safe disposal of all water which could conceivably overtop the crest without danger of contaminating with salt any fresh water stored behind the bank.

(b) The criteria used for design in Phase I are given in section 5.1.4.

(c) It should be noted that, in the multi-purpose schemes proposed, the embankment crest levels are higher than the minimum, due to water conservation levels on the inshore side.

2. Seaward water levels

(a) The maximum level reached by waves on an embankment is given by the combination of predicted tide level, surge, wind set-up and run-up.

(b) Maximum predicted tide level at Liverpool is 17.3 ft O.D. and the highest recorded still water level is 19.8 ft O.D. Surges exceeding 6 ft have been recorded but their peaks have not synchronized with very high tides. Lennon<sup>110</sup> has estimated the 100-year return period high water level, including surge, as 20.0 ft O.D. at Liverpool.

(c) The mean hourly wind speed likely to be exceeded once in 10 years in the Irish Sea has been estimated<sup>119</sup> to be over 70 m.p.h., based on nearly 50 years of records. This must be adjusted before use in estimating set-up and wave heights because (i) it includes winds of all directions, whereas the angular range of full exposure of an embankment in the lower estuary would be about 70° and in mid estuary about half this and (ii) a wind duration of about 6 hours is required for the generation of waves to full height.

(d) Draper<sup>106</sup> in his computation of wave height determined the direction from which the most severe wind would come to be on a bearing of  $310^\circ$  and then estimated the 50-year wind of 6 hours duration from a  $30^\circ$  sector to be 57 m.p.h. The deep water significant wave height was 23 ft which he calculated would reduce to 10.6 ft at the mid-point of the lower estuary and to 6.3 ft in mid-estuary (allowing for a surge to 19.5 ft O.D.).

(e) On this basis, allowing for a run-up ratio of 1.3 on a 1 on 3 rip-rap slope, the 1 in 100 wave at a mid-estuary crossing would reach a level of  $19.5 + 13.5 = 33$  ft O.D.

(f) This method, while indicating maximum wave heights of long return period, should be applied with the following considerations in mind:-

- (i) A return period shorter than 50 years can be accepted for overtopping by waves.
- (ii) The chance of the waves estimated on the above basis occurring at the same time as the highest tides is far less than once in 50 years.
- (iii) The data of winds recorded during the periods of the highest surges show that they were all more southerly than  $310^\circ$  and would not have generated waves reaching the middle estuary directly.

(g) The risk of a bank of given crest level being overtopped could be estimated from data of recorded winds in the Irish Sea. This would be a lengthy procedure and, for Phase I purposes, an estimate has been made with simplifying assumptions, using Draper's refraction and energy loss computation for one case only to derive a frequency diagram based on a 10-year record of winds near Holyhead. The crest levels derived are given in section 5.1.4 (b).

(h) It should be pointed out that while the height of run-up can be estimated with enough accuracy in the case of smooth slopes, on rip-rap slopes it varies considerably with the permeability and thickness of the rip-rap. In the present case, computations of run-up ratio (run-up height: equivalent deep water wave height) based on four

different sources for a deep-water wave height of 8.7 ft and period of 8 seconds varied from 1.1 to 2.0, but it appears from other experimental results that the effect of roughness alone would limit the ratio to 1.45. Taking permeability into account a maximum run-up ratio of 1.3 has been assumed. A better estimate would be made in Phase II by means of model tests reproducing the particular wave characteristics and rip-rap thickness. A berm provided at or near maximum tide level would reduce run-up, but model tests would be required to estimate the magnitude of the reduction.

3. Experience at neighbouring places

Southport, Wallasey, Prestatyn and Rhyl were visited and the local engineers in charge were asked for details of the sea walls and for an opinion on the adequacy of their height. The top levels range up to 29 ft O.D. and general experience was that sloping walls higher than 24 ft O.D. are adequate. This level is about 4 ft above the highest recorded tides and about 10 ft above high water mean spring tides. All four places are sheltered from deep water waves by areas of shallow water.

POPULATION STATISTICS

(a) The tables which follow summarize the projections of the population of Great Britain, by zones, used in the calculations. The projections are compatible with the latest available official statistics and projections, including the statistics of regional population published by the Registrar General in November, 1966.

(b) The regional sub-groups differ geographically in some respects from those in official publications, due to marginal adjustments to suit the computerized traffic model.

(c) Populations in each area for 1981 and, by extrapolation, 2001 have been projected from the adjusted official statistics for 1962. The 1981 projection (total 61.8 million) is broadly in line with those now being made at national and regional levels. The local population figures used in the build-up took account of any firm plans for the housing of overspill. The durability of the proposed investments makes the use of some projection for such a year as 2001 unavoidable; inevitably, the figures (total 73 million) are much more speculative but are thought to be conservatively within the range of present official thinking.

(d) A relative extra growth of local population in North Wales would increase the benefits of a Dee crossing and these have been assessed simply by one test with an extra growth, from 1981 to 2001, of 200,000 people in the area. It might have been logically neater to cull the extra people from elsewhere but this refinement would have been unjustified in view of the limited purpose of the exercise and the margins of error in the general population projections.

(e) Direct application of intermediate yearly population changes, have not been needed in the benefit calculation methods described in the following appendices.

POPULATIONS BY TRAFFIC ZONES

TRAFFIC STUDY ZONE	POPULATION		
	1962	1981	2001
1	4,114,250	4,950,000	6,080,000
2	16,392,930	20,858,000	25,000,000
5	1,502,520	1,977,000	2,617,000
10	2,377,230	2,432,000	2,518,000
13	3,952,800	5,012,000	6,362,000
21	1,686,350	1,934,000	2,248,000
22	368,010	390,000	420,000
25	100,480	110,000	124,000
27	306,150	495,000	720,000
34	506,460	825,000	1,146,000
41	377,630	396,000	403,500
63	115,721	152,000	197,000
65	68,890	85,000	105,000
66	121,290	160,000	208,000
68	585,070	770,000	1,000,500
70	1,408,982	1,265,000	1,084,500
74	1,476,190	1,603,000	1,861,000
77	530,170	613,000	713,000
78	1,772,670	1,904,000	2,068,500
80	981,510	1,237,000	1,535,000
81	172,890	192,000	215,000
82	152,580	213,000	288,000
83	1,304,870	1,487,000	1,717,500
85	361,030	400,000	447,000
87	2,355,820	2,608,000	2,928,000
88	5,196,600	5,659,000	6,230,000
90	171,890	181,000	193,500
98	37,240	50,000	66,000
c/f	48,508,223	57,968,000	68,496,000

TRAFFIC STUDY  
ZONE

## POPULATION

	1962	1981	2001
b/f	48,508,223	57,958,000	68,496,000
101	21,835	25,500	30,500
107	9,300	14,000	20,500
108	11,370	18,500	26,500
111	15,682	18,500	22,500
113	15,180	16,000	17,000
116	21,002	28,500	34,000
118	17,840	22,000	27,500
122	19,816	24,500	30,000
126	13,304	14,000	15,000
128	11,326	14,500	18,000
134	113,130	121,000	137,000
140	107,640	130,000	161,000
157	10,170	15,000	39,000
158	40,355	61,500	86,000
164	5,765	8,500	12,000
168	12,760	22,000	33,000
171	52,980	66,500	79,500
175	2,445	3,500	4,500
178	142,940	160,000	175,000
180	17,892	22,000	26,000
181	14,328	18,000	21,000
182	15,500	17,000	18,000
187	87,990	96,000	102,000
193	167,730	155,000	139,000
196	439,475	373,500	300,000
200	439,475	373,500	300,000
202	99,500	175,000	268,500
204	29,260	92,000	169,500
205	151,750	190,000	238,000
c/f	50,615,963	60,252,000	71,046,500

APPENDIX E1  
(cont'd)

TRAFFIC STUDY ZONE		POPULATION	
	1962	1981	2001
b/f	50,615,963	60,252,000	71,046,500
208	435,280	552,000	691,500
209	19,625	27,000	34,500
210	57,140	123,000	215,000
211	715,487	846,000	1,012,500
TOTAL	51,843,495	61,800,000	73,000,000

TRAFFIC STUDY ZONE	COUNTIES	COUNTY BOROUGHES	MUNICIPAL BOROUGHES	URBAN DISTRICTS	RURAL DISTRICTS
1	Cornwall, Devon, Dorset, Gloucester, Hereford, Somerset, Wiltshire & Worcester (except Salisburies & Stourbridge).	Bath, Bristol, Exeter, Gloucester, Plymouth & Worcester.			
2	Bedford, Berkshire, Buckingham, Essex, * Greater London, Hampshire, Hertford, Kent, Oxford, Surrey, Sussex & Isle of Wight.	Bournemouth, Brighton, Canterbury, City of London (night population), Eastbourne, Hastings, Luton, Oxford, Portsmouth, Reading, Southampton & Southend-on-Sea.			
3	Cambridgeshire, Ely (Isle of), Huntingdon, Norfolk, Peterborough (Isle of) & Suffolk.	Great Yarmouth, Ipswich & Norwich.			
10		Birmingham, Dudley, Solihull, Walsall, Warley (Rushwick), West Bromwich & Wolverhampton.	Salisbury, Stourbridge, Sutton Coldfield, Oldbury, Blacon, Rowley Regis, Tipton & Wednesbury.	Aldridge, Ambleside, Brierley Hill, Coseley, Darlaston, Edgley, Tettenhall, Wednesfield & Willenhall.	
13	Derby (see zone 6), Leicester, Northampton, Nottingham, Parts of Holland, Parts of Lancashire, Rutland & Warwick (outside West Midlands conurbation).	Coventry, Derby, Leicester, Lincoln, Northampton & Nottingham.			
21	Glamorgan & Monmouth.	Cardiff, Merthyr Tydfil, Newport (Mon.) & Swansea.			
22	Brecon, Cardigan, Carmarthen & Pembroke.				
25	Merioneth, Montgomery & Pembrokeshire.				
27	Isle of.				
28	Stafford.	Yarnton-upon-Trent.			
41		Stoke-on-Trent.	Newcastle-under-Lyme.	Biddulph & Kidsgrove.	
63			Croft.	Alsager & Nantwich.	Nantwich & Tatten.

\* Greater London:- London Metropolitan Boroughs, Middlesex, Croydon, East Ham and West Ham.



TRAFFIC STUDY ZONE	COUNTIES	COUNTY BOROUGH	MUNICIPAL BOROUGH	URBAN DISTRICTS	RURAL DISTRICTS
81		St. Helens.		Aston-on-Makerfield, Billinge & Winstanley, Haydock, Orrell, Rainford & Up Holland.	
82		Warrington.		Golborne & Newton-le-Willows.	Warrington.
83		Barrow-in-Furness, Blackburn, Blackpool, Bury & Preston.	Accrington, Bacup, Chorley, Clitheroe, Colne, Darwen, Fleetwood, Haslingden, Lancaster, Lytham St. Anne's, Morecambe & Heysham, Nelson & Rustenstall.	Barrowford, Brierfield, Carnforth, Church, Clayton-le-Moors, Dalton-in-Furness, Fulwood, Grange, Great Harwood, Kirkham, Leyland, Longridge, Oswaldtwistle, Padiham, Poulton-le-Fylde, Preesall, Rawasbottom, Ribbles, Thornton Cleveleys, Trarthen, Tottington, Turton, Ulverston, Walton-le-Dale & Wigan.	Blackburn, Bury, Chorley, Clitheroe, Fylde, Garstang, Lancaster, Lonsdale, North Lonsdale & Preston.
85	Cumberland & Westmoreland.	Carlisle.			
87	Durham & Northumberland.	Burlington, Gateshead, Newcastle upon Tyne, South Shields, Sunderland, Tynesmouth & West Hartlepool.			
88		Scotland			
90	Anglesey & Carmarthen.				
98			Gwynedd.	Aberystwyth.	Aberystwyth.
101				Bigg.	
107					St. Asaph.
108				Preesall.	
111				St. Asaph.	Part of St. Asaph. (25.3%)
113			Douglas.	Lancaster.	Huddersfield.
116			Fins.		Part of Huddersfield. (25.3%)
118				Cannock's Quay.	Part of Huddersfield. (25.3%)
122				Mold.	Part of Huddersfield. (25.3%) & part of Huddersfield. (1.5. 1975).

TRAFFIC STUDY ZONE	COUNTIES	COUNTY BOROUGH	MUNICIPAL BOROUGH	URBAN DISTRICTS	RURAL DISTRICTS
126	Lincolnshire (Lincoln).	Chewer.	Ruthie.		Ruthie.
128				Buckley.	Part of Holwell (28.10%).
134			Wretham.	Langcliffe.	Cairing, Wretham & Menar.
140					Chester: Part of Sewarden (26%).
157				Part of Emscote (25%).	
158			Part of Eldersmore Port (47.5%).		
164			Part of Eldersmore Port (11.8%).		
168				Newton.	
171			Babington.		
175				Part of Wirral (11%).	
178		Birkenhead			
180				Part of Heylake (55.5%).	
181				Part of Heylake (44.5%).	
182		Part of Wallasey (19%).			
187		Part of Wallasey (60%).			
192		Scotie.	Crosby.	Litherland.	
196 & 200		Liverpool.		Hayton-with- Roby, Kirkby & Prescot.	
202			Widnes.		Whiston.
204				Ormskirk & Shearncliffe.	
205		Southport.		Farnby.	West Leamshire.
208		Grimsby.			
209				Part of Wirral (60%).	
210				Emscote.	Part of Emscote (10%).

TRAFFIC STUDY ZONE	COUNTIES	COUNTY BOROUGH	MUNICIPAL BOROUGH	URBAN DISTRICT	RURAL DISTRICT
311		Bolton, Dury, Rochdale & Wigan.	Farnworth, Heywood, Leigh & Radcliffe.	Abcam, Adlington, Atherton, Aspell, Blackrod, Bredley, Horwich, Ince-to- Macerfield, Irton, Kearsley, Little Lever, Milnrow, Standish-with- Longtree, Tyldesley, Westhoughton & Whitefield.	Wigan.

URBAN AND INDUSTRIAL DEVELOPMENTS IN THE REGION

(a) The purpose of this section is to bring out the relevance of an estuary crossing scheme to the urban and industrial development of the surrounding areas. The character of industrial development in the North-West Region is considered first and then related to the present condition and industrial potentialities of the areas of North Wales that a crossing might serve.

(b) While it is always hazardous to rely upon past trends in predicting future industrial development and location, policy decisions must be based on some kind of forecast. There are strong reasons for expecting recent trends in the North-West Region to continue, with a large growth-centre in Merseyside, Manchester and areas between but a continued decline (or at most a relatively slower growth) in the older towns of the east and north-east. The main growth-area now enjoys natural and acquired advantages favouring development, by way of communications facilities (ports and motorway) and diverse industrial and commercial activities, some with apparent development potential (such as electronics and petrochemicals). Added to this, there is the simple stimulus provided by the market generated by the size of the conurbations themselves (present population some 3 million people) and by their expected population growth. There is still some scope for industrial expansion and population growth within particular parts of the growth-area. At the same time, adjoining overspill schemes bordering the area (for example at Leyland/Chorley, Runcorn and Ellesmere Port) tend to reinforce the potential importance of the area.

(c) Outside the Merseyside-Manchester area, the North-West Study<sup>53</sup> suggests the Lancaster and South Cheshire areas as possible sites of future large cities. If the predicted pattern of growth emerges, with its emphasis on the west and south of the North-West Region and on the port area, this must favour the suitability for early development of the more southerly site. It is in this context that the interest of a Dee crossing scheme is enhanced as a means of opening up the North Wales area for economic expansion.

(d) The present characteristics of the Flintshire area bordering the Dee stand in some contrast with the region to the north. The population of Flintshire is less than 170,000. The over-all growth rate since 1951 has been comparable with that of the national population but conceals some marked local differences, with Shotton, for example, growing satisfactorily while Flint and Holywell R.D. show actual population declines. Income levels in the Flintshire area compare

unfavourably with national averages but have been growing rather more rapidly. Other factors (such as the growth of employment) are also unfavourable and in respect of these indicators the Holywell-Flint areas again emerge as specially in need of stimulus if their decline is to be checked.

(e) There are only two large employers (more than 1,000 employees) in the region, both with works in the Dee estuary area and some 23 other firms employing more than 70 workers. There is a port at Mostyn with limited possibilities of future development and a small airport at Hawarden (section 2.2.6). The areas along the sea coast are popular with holiday-makers and there are possibilities of developing more holiday facilities (appendix E8) to cater for the expected population growth (appendices E1 and E7).

(f) The impression gained from direct interviews with firms in the Flintshire area was that the two existing large firms did not expect to be much affected by a crossing. Others were generally optimistic about their present prospects but varied in attitudes to the benefits to be expected. Some firms, particularly those in the west, tended to favour a crossing as a means of reducing their present isolation and "opening up the region". But there was some fear that labour might become more difficult to hold as a result of a crossing, while attitudes to the alternative possibility of labour immigration were also mixed. What happens in these respects would be influenced by the kind of planned development that was decided upon but it is noteworthy that Flintshire now seems to have a net inflow of commuters (that is, there are more jobs than resident workers). Industry in the area would clearly be strategically situated for the movement of goods; even the more distant Birmingham conurbation is expected to increase shipments through Liverpool by 45 per cent in the next fifteen years, most deliveries being by road.

(g) The detailed study of the growth-potential of North Wales and its relation to an estuary crossing lies outside the terms of reference of the present study. This is restricted to the effect that population or industrial change in this area might have on the benefits from a crossing and does not extend to consideration of whether the crossing itself might encourage such further developments. A broader study would require firmer knowledge of development plans for the region than is yet available. It would also require a study of at least the same order of technical difficulty as the present one. (This is not of course to suggest that no interest has yet been shown in the development of the area. For example, various suggestions have been made about possible industrial development, ranging from the view that the area might be more suitable for

light engineering than further concentration in Merseyside, to suggestions that there might be scope for heavy industry, for petroleum distribution (storage) depots and for ancillary developments by firms already located in Merseyside. There has also been discussion of the need for some stimulus to mid-Wales as a whole).

(h) The benefits of a crossing and the development of the Welsh side are clearly inter-related and, while the present study is limited to estimation of the benefits and costs directly related to a crossing (such as traffic and water benefits, land reclamation, effects on amenity, agriculture and fisheries), a balanced view must take account of all the implications. The fact that some remain unquantified does not imply that they are to be treated as insignificant. Indeed, it is the import of this description of the Dee region that, underlying the specific and direct benefits to be examined, there are other and perhaps major general considerations to be borne in mind, related to the development possibilities and problems of the two sides of the estuary. For example, a crossing might make North Wales a potential substitute (or partial substitute) for the South Cheshire development. On the one hand, it might provide a valuable stimulus to the economic development of North Wales and, if wisely planned, could do so without detriment to the amenity of the area. On the other hand, the possibility is created of preserving (perhaps even improving) the amenities of the Wirral region and of maintaining a Green Belt and agricultural area serving both the northerly conurbation and the developing Welsh side. While judgement should not be made in this report on these larger possibilities, it is clear that the recommendations made (and, indeed, some of the valuation procedures adopted, notably in relation to land) must be read with them constantly in mind. Clearly some attempt will have to be made to relate an estuary scheme to more detailed study of the relevant regions and to explicit programmes for regional development.

CALCULATION OF BENEFITS FROM ROAD CROSSINGS1. Introduction

One of the major arguments put forward in favour of a Dee estuary crossing is that it would quicken communication between North Wales and the Wirral, Merseyside and areas beyond. To estimate the benefits from a crossing, it is necessary to define the nature of costs of road travel in the area and how these would vary with alternative schemes.

2. The effect of a crossing on costs to road users

(a) At present, for example, a road vehicle travelling between Liverpool and Rhyl follows a circuitous route. The costs (e.g. fuel, depreciation of vehicle, loss of time) of the journey depend upon the distance travelled and the time taken, the latter in turn depending on congestion along the route. While the distance travelled on a given route remains constant, the time taken will vary with the time of day and year, an important local factor being the peak periods in summer.

(b) Traffic imposes other important costs on the community of a less tangible kind, such as accidents of varying severity, inconvenience caused by fumes and noise, delay to pedestrians and loss of landscape amenity. For the purpose of Phase I comparisons, it has been assumed that the incidence of these costs would be similar for all the proposed schemes but they must be borne in mind when comparing benefits with costs.

(c) Given the growth in population and car ownership and other local changes in economic structure referred to elsewhere, road travel costs will clearly rise unless the road system is much improved. Even if the existing road system is improved by widening and better surfacing, congestion could still get steadily worse, for rising incomes alone mean that the number of vehicles on the roads per head of population will continue to increase. With the present road system, motorists can avoid congestion only by wide and costly diversion.

(d) Any of the proposed estuary crossings, especially one combined with the scale of other improvements already projected, would reduce road-user costs by shortening both distance travelled and journey time. On the other hand, the crossings and associated improvements would themselves generate more traffic and any calculation of cost savings should take this into account. Although some of the road improvements now projected may need slight modification in the light of an estuary

crossing, the over-all improvement costs would be similar and the network assumed in the traffic study would be unaffected.

### 3. The measurement of benefits

Measuring the benefits of the road crossings is a 5-stage operation. Current formulae and practice are used and the calculations are simple, refinements being unjustified in view of other limitations in the study. This may also facilitate comparison with studies of traffic benefits for other schemes. To save including similar material elsewhere in the text, the stages are described and their limitations stated or implied in discussion of what might be included in the next phase of the study.

#### Stage 1 - Traffic composition

Traffic composition in the Dee area does not differ much from the recent national pattern, as shown in the table; the national pattern is therefore assumed in the calculations to apply, since this also allows the use of parameter values already derived by others (see below).

Class of vehicle	Typical vehicle	Average composition on all roads (1963)	Average composition near Queensferry <sup>10</sup> (1961)
Car	1750 c.c.	%	%
Public-service	44-seater bus	3	3
Light commercial	10 cwt. petrol	14	8
Medium commercial	4 ton, diesel	14	19
Heavy commercial	10 ton, diesel		

% includes motor cycles

#### Stage 2 - Cost per mile

(a) An expression for the cost per mile ( $C_m$ ), suitable for use in Phase I calculations, is of the linear form :-

$$C_m = A + \frac{B}{V}$$

where A is the sum of these costs assumed to be constant over a given range of speed, B, expressed in terms of cost per hour, is the sum of costs directly proportional to hours spent on travel and v is the speed in miles per hour<sup>35</sup>.

(b) The following information on cost per mile at 1962 prices for average national traffic composition was received through the Welsh office :-

$$C_m = 4.4 + \frac{218}{v} \quad \text{pence (v < 37 m.p.h.)}$$

$$C_m = 5.0 + \frac{196}{v} \quad \text{pence (v > 37 m.p.h.)}$$

The average speed has been found to be about 40 m.p.h. and the second formula is used, an adjustment being made to express the values in current (1966) prices. The constant term of 5d/mile consists (approximately) of 30% fuel, oil and tyre costs and 70% those proportions of the maintenance and depreciation costs which vary with speed. The numeration of the second term is essentially a weighted average opportunity cost of time spent in travelling. The adjustment is made by application of three 1966 : 1962 ratios of appropriate price indices<sup>63</sup>, giving :-

$$C_{m66} = 5.6 + \frac{252}{v} \quad \text{pence}$$

(c) For Phase II, an evaluation should be made of some of the assumptions behind the formula since the linear variation in costs applies only over a limited speed range; for example, fuel costs will rise as average speeds increase beyond some critical speed level. Thus a more general form of the equation might be

$$C_m = A + \frac{B}{v} + f(v)$$

where A, B and v are defined as before and f(v) is a separate term describing costs per mile related to speed in a more complex manner. It would be worth investigating whether the obvious convenience of using a linear approximation should be foregone.

(d) As the most important component of B is travelling time saved, particular attention needs to be paid to its valuation. The first step in this process is to obtain information on the occupancy rate of different classes of vehicles, for time savings affect occupants as well as drivers. There are no special problems here, but to determine whether the time saved is working or non-working time is more difficult. In the Phase I calculations three-quarters of the time savings

for cars is assumed to be in non-working time, but time savings for commercial vehicles are regarded as working time. Boorman<sup>31</sup> argues that it may not be reasonable to assume that all time saved in commercial vehicle operation will be spent on 'useful running' so that some part of it at least must be valued as non-working time, i.e. at less than the driver's current hourly wage rate. It is difficult to predict the effects of future time savings on the working schedules of commercial fleets and to value them may be almost impossible. A further difficulty lies in the valuation of non-working time. The Phase I calculations assume that non-working time for car drivers and occupants is valued at  $\frac{2}{3}$  of an assumed hourly wage rate. Unlike the commercial operator's time, that of the occupant of a private car is not bought and sold, so the adoption of  $\frac{2}{3}$  (or for that matter any other fraction) of working time is a purely arbitrary practice. Indeed, valuations of non-working time have varied in recent traffic benefit calculations from nil to the full hourly wage rate. In Phase II, it is suggested that both working and non-working time savings might be calculated for a range of values, as in the London-Birmingham Motorway study<sup>32</sup>.

#### Stage 3 - Annual savings to diverted traffic

(a) The formula is now used to calculate diverted traffic savings i.e. savings to traffic which would flow even if no crossing were built. At this stage, the traffic flow predictions (appendix C4) are fed into the formula. The method adopted is illustrated by taking the middle zone crossing in 1961 without a third Mersey crossing, for which savings of 23,353,900 vehicle miles and 2,354,500 vehicle hours have been estimated giving £3.017m.

(b) This is the figure of cost savings at 1966 prices. It has to be modified to allow for generated traffic before the final total can be used as a point on the time stream of benefits.

#### Stage 4 - Annual savings to generated traffic

(a) Estimates of generated traffic are also contained in appendix C4. The minimum saving to generated traffic is at least equal to the cost of the journey by the new route and the maximum saving may equal the cost of the journey on existing roads. The total saving to generated traffic is therefore taken to be half the difference between the costs of the journey by the existing route and by the new route.

$$\pounds \frac{1}{2} \times \frac{12,200}{23,600} \times 3.017\text{m} = \pounds 0.780\text{m}$$

(b) Phase II analysis might refine this calculation in two ways. Firstly, the traffic flow predictions in Phase I have measured traffic generated only by the introduction of a crossing and not traffic generated by reduction of congestion on other roads in the system. It is important in a more detailed study of cost savings to know the savings to generated traffic throughout the full road network. The second refinement is in the analysis of the effects of generated traffic throughout the whole network on speed of travel of all traffic. If generated traffic reduces speed of travel significantly, the savings per diverted vehicle may be less than if there were no traffic generation.

#### Stage 5 - Present values of savings

(a) To express cost savings in terms of present values, further calculations have to be made. Traffic flow and cost saving predictions up to this stage have been made for specific future years. Savings for intermediate years in the study period must be interpolated. The combined effects of population growth and assumed trips per head "saturation" curve were found to approximate to a straight line between 1976 and 2001. The savings would follow similarly and a straight line 'value stream' was drawn through the 1981 and 2001 points and drawn back to 1976.

(b) The total undiscounted value of cost savings for the period 1976 to 2001 amounts to £115.0m.

(c) Discounted at 8 per cent the present value of cost savings for the example becomes £44.6m.

(d) If the population did not increase after 1976 the benefits would be reduced by about 20%.

#### 4. Further considerations

(a) No allowance has been made for the 'intangibles' mentioned in 2 above but the Phase II calculations might take account of the possible effects on accident rates of changes in traffic flows throughout the road network and therefore on costs.

(b) While standard practice of regarding reduction in costs as a measure of benefit is probably reasonable for both Phase I and Phase II calculations, it is pertinent to the study to point out how the one is transformed into the other. Cost savings confer two sorts of benefit:

the same number of journeys could be performed and the reduction in costs would allow an increase in the purchase of other goods or in the amount available to be saved, or more journeys could be undertaken for the same expenditure or some combination of both these possibilities could take place. In placing a monetary value on the benefit of cost saving, therefore, there are two possible measures (1) how much income would the traveller be willing to give up rather than have the cost of journey returned to its previous level ? and (2) if the cost of journey returned to its previous level, how much income would he have to be given in order to make him just as well off with his previous income, at the new reduced cost? Unfortunately, these two measures do not yield the same result and neither corresponds with the result obtained simply by measuring the total cost savings. There is little reference to this problem in empirical studies of the economics of communication improvement, because only a small error may result from adopting cost savings as a measure of benefit, provided that journey costs are a small proportion of the total input costs of commercial concerns or of personal incomes.

(c) Again, consider an industrial undertaking which has its own transport fleet. Road improvements will reduce the costs of transport, but who will benefit from this depends on the reaction of the undertaking to the reduction in costs. It may pay it to pass on the benefits wholly or in part to buyers of its products, for by doing so it may attract custom. On the other hand, if such an increase in custom is unlikely, it may leave its prices unaltered for a while so that the cost savings directly increase profits. In translating cost savings into benefits, no judgement is passed here on the desirability or otherwise of the resultant distribution of those benefits. This, however, may need further consideration in Phase II.

(d) Finally, it is assumed in the calculations that the road system existing in 1981 will continue unchanged until 2001. This is manifestly unrealistic but, while further improvements after the building of a crossing must affect the traffic flows across it, any resultant benefits constitute a return on the investment in the improvements. The crossing once built becomes a part of the country's capital stock in transport, the whole of which is a datum when further road investment policy is decided. Plans for road improvements after 1981 do not exist, so that the difference a crossing might make to these cannot be taken into account. All things considered, therefore, the choice of the 1981 traffic network to measure benefits up to 2001 is not misleading in any important way and is certainly superior to any alternative procedure available.

TOLLS

(a) The results of an assignment on the traffic model for the middle zone crossing in 1981 using a toll of half a crown for all vehicles is given in table 2 of appendix C4.

(b) The yield from the toll in that year would be £676,000 with the third Mersey crossing and £536,000 without. Using the same ratio for traffic on a middle zone crossing with and without a toll, in 2001 as in 1981, the yield from the toll in 2001 would be £1,022,000 with the third Mersey crossing and £834,000 without.

(c) Yields in other years were derived by drawing a straight line through the points for 1981 and 2001 back to 1976. The present value of the yield of the toll from this 25-year time stream would be £6.8m with the third Mersey crossing and £6.3m without.

(d) The cost of collecting and administering the toll has been taken as 25% of the yield from the toll. Thus the present value of the net yield of a toll would be about £5.1m with a third Mersey crossing or £4.7m without.

(e) The present value of the cheapest embankment crossing with a small bridge over the ebb channel would be £14m not counting a further £7m for approaches. It seems unlikely, therefore, that a crossing with a half crown toll could be paid for by that means.

(f) A detailed study of the implications of a toll, if still considered desirable, would comprise an investigation into the effects on traffic of varying levels of toll for each vehicle classification within the context of appendix C5.

CALCULATION OF BENEFITS OF WATER SUPPLIES1. Introduction

The most intractable valuation problem attempted in the study has been that of measuring the benefits from development of the water resources. Yet in order to assess the viability of any scheme, these benefits have to be valued since the development costs are a large element in the investment decision. Although, in the event, the problem has been solved for Phase I purposes by reasonable assumptions and by use of the "opportunity cost" concept, it is useful for future reference to outline the various difficulties and steps taken before giving the calculation results.

2. ValuationLack of a market for water

(a) There is no market for water in the usual sense of users being charged prices that are responsive to the pressures of supply and demand. Most supplies are not metered (priced) and the widespread practice of average-cost pricing means that charges for metered supplies give little indication of what users would be prepared to pay for existing supplies or of the value which they place on new increments of supply.

(b) Apart from metered supplies, a semblance of a market exists in that water undertakers will normally seek and promote only those schemes which will give them the cheapest available water of good quality. Since transmission can form a major element in water cost (see later), it follows broadly that they will favour a source near their supply zone or, indirectly, a source such as a river regulating reservoir, the yield from which they can abstract from the river near their supply zone.

Opportunity cost of water

(c) While it is outside the scope of this study to examine the methods of charging for water, it is clear that they provide no basis for the valuation of future supplies. Yet a unit value of water is required, in order to generate a revenue stream that can be discounted to obtain a present value for the amounts of water assumed to be supplied in each future year. In the absence of a market price for water, a "proxy" for price has been obtained by using the concept of "opportunity cost". By this method the value of water from Dee estuary schemes is taken as being not less than the costs of meeting demand in the region of the Dee from more distant sources of sufficient capacity and, ultimately, from desalting of sea water.

(d) The opportunity cost method of valuation is not ideal but simply the best alternative to market price. It is given practical plausibility by the fact, mentioned above, that water undertakings seek the cheapest available sources of supply. It is also believed to understate the present value of Dee water, because a market price would almost certainly be higher than the opportunity cost proxy that has been taken, if only because the proxy carries a rate of return on capital lower than would be expected to accrue to the resources of labour, plant and materials for water supply if used elsewhere in the economy.

#### Geographic limitations

(e) Whilst a Dee estuary water scheme is significant to the country's future supplies as a whole and certainly to the adjoining regional supplies, means have been found of making a preliminary valuation of the scheme without extending the study outside the present Dee supply zone. Given the special position of the estuary in relation to North Wales and the Merseyside conurbation and knowledge of the regional resources and demands, reasonable and generalized assumptions as to "opportunity costs" of supplying the Dee's "natural" area could be postulated (and should be reviewed in due course in the light of strategic planning by the Water Resources Board\*). If for social or economic reasons, no cheaper alternative to Dee water is available to some point outside the "natural" area, the value of Dee water at that point is by definition increased by more than the extra transmission costs involved. This result follows from the opportunity cost principle, which values water by reference to alternative sources of supply.

#### Subsidy of water

(f) In effect, water supplies are subsidized because the rate of return on capital invested is well below that in private industry and, indeed, below that now expected in nationalized industries.

#### Sewage and waste disposal

(g) Costs and benefits associated with sewage and waste disposal resulting from provision of water supplies have implications which are too wide to be considered fully in this report. They are relevant, however, to a full economic study of a river's water resources especially where appreciable effluent returns are made to the river and contribute to the quoted water yields.

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\* At the time of going to press with this report, the Water Resources Board's publication no. 4 was issued by H. M. S. O. and is considered to confirm the assumptions.

Ancillary benefits from water

(h) Lakes and water supplies in the Dee estuary would provide other benefits which either cannot be valued in money terms at all or should anyway be listed as intangibles:-

- (i) amenity
- (ii) recreational facilities
- (iii) use for reservoirs of areas of estuary rather than agricultural land elsewhere
- (iv) inducement to industry to expand near a major port, hence reducing national transport costs.

3. Methods of measurement of costs and benefits

Sub-division of costs

(a) Costs of water supplies can be divided into capital and running costs of:-

- (A) raw water
- (B) treatment
- (C) transmission (pumping and bulk distribution) up to but excluding service reservoirs
- (D) terminal or service reservoirs and local distribution and pumping
- (E) administration and other overhead costs.

(b) All these costs are relevant to an economic assessment of a multi-purpose scheme and should be added to other costs such as traffic and land usage, to be set against total benefits of the scheme, including water. In this study, however, costs for items (D) and (E) have not been included and, for the purpose of determining the opportunity costs, they can be ignored since for given areas of demand they are broadly constant for any source. Indeed, as direct-supply reservoirs providing relatively pure upland water become the exception rather than the rule (as in the past) and, in any case, as treatment works sizes become larger and hence cheaper for lowland sources, item (E) becomes less variable.

(c) Thus items (A) and (C), especially the latter, govern the economic choices, coupled with considerations of the ultimate capacity of the source in relation to demand and its divisibility into economic stages to match supplies with demand i.e. to provide at any time a minimum of surpluses having a zero value - apart from value for amenity, recreation or as strategic reserve.

#### Discount rate

(d) A discount rate of 8% has been used throughout the calculations.

#### Unit costs and prices

(e) The price derived from the opportunity cost is applied to the supplies that would be required from an estuary scheme in each future year to give the annual value of the supplies (i.e. revenue stream). These values are then discounted to the date of the end of the first stage of construction (taken as 1976) to give the present value. A useful short cut is to discount the annual quantity of water supplied and then apply the price expressed in pence/1000 gallons to give the present value of the benefit.

(f) For generating future revenue streams for discounting purposes on opportunity cost principles, costs of alternative supplies quoted in pence/1000 gallons as they stand are unsuitable and need re-calculating for two main reasons:-

- (i) there would be a "circularity" in discounting figures which already embodied allowances for amortization over some chosen periods at a rate of interest (e.g. 7%) similar to the discount rate;
- (ii) the costs may have been derived simply by dividing the annual costs (loan charges, operation and maintenance, with or without sinking fund and with or without interest during construction) by the final annual design yield; or, similarly, but refined to average the costs over each of two or more stages; or, further refined in the form of falling curves (or series of curves to suit staged construction) of unit cost against time, to show the higher unit costs before demand reached the supply available i.e. taking account of initial surpluses. Further, these unit costs may range anywhere between representing those of raw water at source and treated

water at the tap; for desalting, they may be for distilled water (untreated) at the plant outlet i.e. by the sea and at little more than sea level.

(g) Thus the conventional concept is misleading in an economic assessment of individual schemes and in a choice between alternative schemes, including the time profile of water supply in relation to the estimated growth of demand. It is suggested that unit costs of water should instead be expressed in "present value" pence/1000 gallons or, say, pvd/1000g at any point - which must be stated - in the supply chain between the raw water source and the tap.

(h) This method differs from the conventional approach in that the present value of the capital cost of the works plus interest during construction and running, maintenance and replacement costs, is then divided by the discounted annual quantities of the water supplied to give pvd/1000g.

(j) Where the unit cost of water relates to works that can be staged to reduce surplus capacity (e.g. treatment works or a succession of small reservoirs), the pvd/1000g will remain roughly constant for varying rates of increase in demand.

(k) Transmission is more difficult since with long pipelines the high initial capital cost of a large diameter pipe is offset, for a gradually increasing demand, by the low pumping costs in the early years. For the lengths and flows considered in this report the pvd/1000g of transmission would remain roughly constant for varying rates of increase in demand.

(l) It is in the unit cost of raw water sources that the concept of pvd/1000g is most revealing. A single stage scheme with low running costs would have a roughly constant present value of costs however long a period elapsed before the full reliable yield was supplied and yet the present value of the water supplied would vary widely. If the full reliable yield could be used on completion of the scheme, the pvd/1000g would equal the conventional pence/1000 gallons but, if a long period elapsed before the scheme could be fully used, the present value of the water supplied would be lower and the pvd/1000g correspondingly higher.

(m) Thus the pvd method has the major advantage of taking account of surplus capacity.

4. Calculation of opportunity cost

(a) The opportunity cost for the lower rate of increase in demand (5 mgd per year) derived in appendix D2 has been taken as the cost of supplying Liverpool from some (unspecified) alternative northern sources with 150 mgd after 30 years followed by supplying the whole of the Dee's natural area with 150 mgd of desalted water by the end of the next 30 years.

(b) The existing authorized resources of Liverpool and Birkenhead, if reallocated, would meet the deficiencies in the Dee basin and thus alternative supplies to Liverpool would have the effect of meeting the deficiencies in the whole of the Dee's natural area without incurring extra transmission costs.

(c) The cost of these alternative supplies has been taken as 30 pvd/1000g for items A, B and C above which, with the linear increase in demand assumed, gives a present value to perpetuity of £34.6m.

(d) The natural area of demand for the Dee could be supplied by a number of desalting plants on the coast close enough to keep the costs of (C) transmission, to perhaps 6 pvd/1000g and, taking a low estimate of the costs of A and B for future desalting at 30 pvd/1000g, the present value of the alternative supplies for the second period of 30 years is £4.1m. It should be noted that errors in the forecast of the cost of desalting lose their significance when deferred for this length of time.

(e) Thus the opportunity cost of water supplies from a Dee estuary scheme which gives 300 mgd after 60 years of development has been taken as £38.7m.

(f) The opportunity cost of the higher rate of increase of demand (10 mgd/year) derived in appendix D2 has been taken as the cost of supplying the northern boundary of an extended area of demand from alternative sources with 300 mgd after only 30 years development. In this case desalting does not have to be considered as the cheapest alternative and, for the same reasons as for the lower rate of increase of demand, the cost of supplies to the whole of the extended area could also be taken as 30 pvd/1000g, which gives a present value of £69.4m.

(g) The present value of the benefits calculated in this way are smaller for the longer period of growth of demand. It should be borne in mind, however, that the present value of the costs will also be less for a scheme of staged construction.

(h) Other assumptions for the unit costs of alternative sources may be tested by making pro rata adjustments to the present values.

(j) These benefits would also accrue if the next increments of reliable yield from the Dee catchment were obtained from further upland storage before utilizing estuary storage. (The costs, however, would not be the same).

#### 5. Unit costs of Dee estuary water supplies

(a) Multi-purpose allocation (see also part 4) is needed only for illustrating unit costs of Dee estuary water supplies.

(b) Since water supply is not the only benefit to be considered, the whole of the discounted values of capital costs and of annual operating costs cannot be allocated to water. A similar argument can be applied to traffic, land or other benefits.

(c) Although conceptually there is no separate cost of any single benefit in a multi-purpose scheme, an upper limit to the costs attributable to water works can be given if the costs of separate schemes, designed to satisfy each of the multi-purpose demands in turn, total more than the cost of the multi-purpose scheme itself.

(d) In the case of estuary schemes the cost of pure water and pure road schemes always add up to more than the corresponding multi-purpose scheme without having to consider reclamation or amenity schemes.

(e) If the estuary were used only for water conservation the cost of such a scheme would give an upper limit for the unit cost of water from a multi-purpose scheme. It has been estimated that the present value of a raw water scheme for this full use of the potential yield of 300 mgd after 30 years would be about £20m, including interest during construction and running, maintenance and replacement costs. The present value of the costs of treatment would be about £11m. The characteristic transmission distance and static head encountered would be 30 miles and

and 300 ft respectively and the present value of the cost of delivery would be about £24m. Similarly the present value of the water that could be supplied would be 550,000 million gallons.

(f) If the potential yield were not fully utilized for 60 years the present value of the costs would be about £13m, £6m and £11m for water conservation, treatment and transmission respectively. In this case the characteristic transmission distance would be 24 miles and to the same static head of 300 ft. The present value of the water that could be supplied would be 300,000 million gallons.

(g) The resulting unit costs of water are :-

	30 years development pvd/1000g	60 years development pvd/1000g
conservation	9	10
treatment	5	5
transmission	10	8½
<b>totals</b>	<b>24</b>	<b>23½</b>

(h) For comparison, the conventional unit cost of raw water from an unstaged Dee estuary water scheme would be 5½ pence/1000 gallons (interest rate of 8%, amortisation over 60, 40 and 20 years for earth-works, concrete works and plant respectively). With treatment and transmission costs added, the unit cost becomes 20½ pence/1000 gallons or 19 pence/1000 gallons for 30 or 60 years development. With an interest rate of 7% the figures become 5 pence, 20 pence and 18½ pence/1000 gallons respectively.

LAND VALUATIONSEffects of engineering changes

(a) The engineering changes introduced by the schemes cause the estuary area and North Wales to be better served by communications, water supply, amenities and recreational facilities - in particular the land is generally more accessible from other places such as the Merseyside conurbation. A major benefit flowing from the scheme would be the stimulus provided for economic growth in North Wales. Clearly this growth would be reflected in an increased demand for land in the developing areas and the land aspect of the above benefit, resulting directly from the locational advantage conferred by the scheme, would be the more efficient use of the land generally.

Changes in the availability of land

(b) A scheme would also affect the amount of land available in several ways :-

- (i) land outside the estuary would be used in the scheme (notably for the building of approach roads) and loss of the present or alternative uses of that land would be a cost to the scheme;
- (ii) the availability of some land within the estuary would be affected. Some land would be "used up" directly, for example, by having embankments built upon it and, again, loss of its use for other purposes would be a cost to the scheme.
- (iii) Land reclaimed (i.e. made available for new uses) is a benefit from the scheme.
- (iv) If land would be reclaimed automatically e.g. by the building of an embankment, the use of such land for reservoirs or meres is a cost to the scheme.

The valuation problem

(c) The most general and difficult land valuation problem concerns the identification and measurement of the consequences of the engineering changes since these affect all other land in the region as well as the specific categories described in the last section.

(d) Whether a crossing is built or not, land values generally must be expected to increase under the pressures of population growth, rising living standards and industrial growth. Ideally, a measure of the benefit (in this context) from the presence of one of the proposed estuary schemes would be the resulting reduction in that general rise in land values, plus any net benefit or cost from changes in the actual amount of land available.

(e) Although this benefit from engineering change is thus a differential, it could still be substantial in that housing and industrial development could occur on land other than scarcer land in the conurbations, potential Green Belt or high-grade agricultural land.

(f) It is well beyond the scope of this study, however, to put a value upon this differential. In the first place, the geographical pattern of future urban and industrial change (and hence of land values) will be determined, not simply by market forces but by fundamental planning decisions which have still to be taken.

(g) Again, a study including such benefits would have to be related to alternative public investments studied in the same way and which, although they need not be concerned with river crossings, might result in similar engineering improvements (and changes in land values) in other areas. A consistent basis for comparing schemes at this level of sophistication is not available. To provide one, would introduce formidable problems which clearly could not be examined within the context of a single investment possibility.

(h) Thus it has been thought most sensible to draw attention to the general benefit of engineering changes but to make no attempt to quantify it. This procedure may well lead to an appreciable under-estimate of benefits but it has the advantage of keeping the benefit-cost calculations simple and of presenting them in a form that facilitates comparison with other studies.

#### Valuation procedures

(i) If the effects of engineering changes on land-values are ignored, land benefits and costs can be assessed at values of land for agricultural purposes, since this type of use is dominant in the area. Reasonable average prices for second and lower grade agricultural land have therefore been used, as appropriate, in the estimates. This procedure is realistic provided that enough land is available for development for no one acre, sold for any purpose, to command a price markedly higher

than other acres remaining in agricultural uses. The procedure becomes increasingly unrealistic as the scope of induced development grows. (The market value of agricultural land is higher than it would otherwise be because of the subsidies attracted by agricultural activities. For the purposes of this study, however, it is plausible to treat such subsidies as having the purpose of bridging an assumed difference between the social (community) and the private benefits from agricultural activities, so that prices as affected by the subsidies are a proper measure). On this basis :-

- (i) Land used for the scheme outside the estuary has been included in the calculations at agricultural market prices.
- (ii) All land in the estuary is owned privately or by public authorities and would fetch, in the open market, some price which would be lower by far than that for neighbouring agricultural land. If estuarial land is buried under embankments or otherwise made irreclaimable by a scheme, its loss to other uses should be treated as a cost. This would be a matter of importance to landowners and would clearly have to be examined in due course. For present purposes, however, the total value is negligible relative to the general cost and benefit magnitudes under examination. (It is an advantage of an estuary road scheme, relative to road improvements of other kinds, that the latter would use land of better quality).
- (iii) The gain to the community from estuary land being left dry has been valued at a high average value as agricultural land, less its present market value. The reason for taking a high value is simply in order to demonstrate that it still gives a relatively small benefit. It is understood that the benefit to the community from investment in Dee estuary agricultural reclamation would be much less than that to be expected from other forms of agricultural investment. Any incidental reclamations of existing high marshes, however, could be converted to reasonable agricultural use at fairly low cost.
- (iv) The land covered by reservoir water is treated as in (ii) above for the following reasons.

The reservoirs would occupy land that could otherwise be reclaimed if river training and/or estuary enclosure works were carried out. As stated in paragraph (b) (ii), it follows that the rate of valuation being attributed to reclaimed land should also be used to assess the loss

suffered by using the land for reservoirs. Effectively, land now valued as tidal flats (low cost), is reclaimed (given a higher value) and then used for reservoirs at a cost equivalent to its reclaimed value. The net effect is still a low cost of land for water conservation.

The magnitudes concerned are not significant, anyway, but attention is drawn to them because they illustrate an important implication of the valuation procedure. To the extent that the method used to value reclaimed estuarial land might be conservative, the use of such land for water storage might be thought to impose higher costs (losses of land to other uses) upon the community than have been shown. As an offset to this, higher values for estuarial land must result from the development of the immediate estuarial region and this, in turn, must increase the value of a local water supply. Thus the schemes presented need to be interpreted with these reservations in mind, particularly when deciding the amount of land to be set aside for uses other than roads and water conservation.

- (v) Land covered by water for amenity and recreation purposes has similar implications to land under reservoirs (see paragraph (j) (iv)). These uses of land are more fully discussed in appendix E7.

#### Distributional considerations

(k) It will be evident from the above that any scheme decided upon will confer gains and impose losses on the owners of land in particular locations. These "distributional" considerations have not been pursued in this study but would doubtless be considered in due course.

AMENITY AND RECREATIONAL CONSIDERATIONSGeneral

(a) An estuary crossing and its results would affect both the amenity and recreational facilities of the Dee area, particularly if the crossing formed part of a multi-purpose scheme. Some results would contribute to, others detract from, these facilities and an improvement in one area might be a detriment to another. For example, the view of the Flintshire shore and mountains over the estuary from the Wirral would be adversely affected if the crossing resulted in industrial or urban development on the Flintshire side but, on the other hand, the facilities of the Wirral shoreline would be improved if multi-purpose schemes brought back water to places that have been suffering from gradual but continuous siltation, although, as a result, siltation might be encouraged elsewhere. Recreational facilities such as boating and fishing could be created but possibly at the expense of existing similar facilities which are lost.

(b) The way in which any multi-purpose scheme is staged would also affect both amenity and recreational facilities. Thus, reservoirs built in stages would reduce water supply investment costs but at the expense, in the meantime, of the amenity and recreational facilities of the larger lake provided by a single stage scheme.

Valuations of amenities and recreational facilities

(c) A mere on the Wirral shore would be an important amenity feature of certain schemes. To build a mere of the order of size indicated on the drawings at the start of a scheme, rather than wait as long as thirty years before it was developed incidentally from staged reservoir construction, could cost up to £1 million (present value). This apart, money values have not generally been placed in Phase I upon amenity or recreational facilities. For reasons which follow, only the consequences of the different schemes are noted, so that any decision for further study or to proceed with a particular scheme can be taken with these in mind.

(d) The benefits derived from amenity and recreational benefits fall into two categories :-

- (i) Those which have a value to the community but which cannot be valued by normal market criteria.
- (ii) Those for which a value, if only in part, can be established by normal market criteria, the remaining part falling under category (i).

(e) The view of the Welsh mountains provides a good illustration of category (i). Houses with a good view of the mountains are likely to fetch better prices than those without. The value of the view to the community, however, cannot be assessed simply by reference to such quantifiable benefits. The view has the characteristic of a "public good" to the extent that one person can enjoy it without diminishing the possible enjoyment of another. Conversely, the unsuitable location of a factory may diminish an amenity for a whole community but, again, ordinary market concepts cannot be used to evaluate the loss. The existence of such indivisible benefits and costs is one justification for planning procedures (such as those created by the Town and Country Planning Acts) which ensure that private decisions take account of these factors.

(f) Sailing provides an obvious example of benefits under category (ii). It is not hard to devise a method of levying charges on vessels wishing to use a facility. A difficulty arises however, in that the use of such facilities is not normally charged for, or is charged at a price not determined simply by the demand for them. The price that people would be willing to pay for a particular facility is therefore an imperfect measure of community benefit, unless the use of similar facilities is actually being restricted by charges, in which case a value can be derived. A further problem is that demand has to be forecast for facilities (such as fresh water sailing) which are limited at present in the area but which would be created by a multi-purpose scheme.

#### Conclusions

(g) Methods have been suggested for valuing the benefits from amenities and recreational facilities <sup>57, 59, 61</sup> using such factors as the size, density, incomes and urbanization of population in relevant areas and the distances travelled to enjoy the amenity. These methods might apply to the part valuation of benefits under category (ii) in paragraph (d), but are not entirely satisfactory even for a Phase II study.

(h) In Phase II, the indivisible benefits of amenity and recreation would be hardly worth trying to measure but some of their distributional implications might be examined. An evaluation, if required, of other benefits from recreational facilities such as sailing, could be based upon assessments of the likely demand.

(j) Even if their benefits are not measured, amenity and recreational considerations may nevertheless have weight in decision making, particularly when the choice between alternatives is marginal.

THE EFFECT OF A DEE CROSSING ON THE WELSH  
TOURIST AND HOLIDAY INDUSTRY

1. Size of the holiday industry

(a) The Council for Wales has estimated that in 1961 well over four million holidaymakers from England and Wales spent nearly 6 million holidays in Wales. The survey on which this estimate was based did not include visitors from Scotland and from overseas.<sup>(1)</sup> Estimated spending of £50 million made tourism the fourth largest industry in Wales (in terms of contribution to national income).

(b) The growths of population, income and leisure are all leading to an increase in the number of holidays taken but, in recent years, an increasing proportion of holidays have been taken abroad. It is, therefore, expected that in the absence of major policy changes, the number of holidays taken in Wales will increase slowly, to about 7 million in 1980.

(c) Rather more than 60% of visitors to Wales take holidays in North Wales; the North is much more sparsely populated and less industrialised than the South, so that the holiday industry is relatively of much greater importance.

2. Characteristics of the Welsh industry

(a) The Welsh industry differs from that of other parts of Britain in several important respects :-

Type of accommodation

(b) Hotels and guest houses take a proportion of visitors well below, and caravans and camping well above, the national average. The following figures show the proportion of visitors using different types of accommodation.

	%	
	<u>Britain</u>	<u>Wales</u> <sup>(2)</sup>
Hotels and guest houses	42	32
Friends and relatives	25	17
Caravans	14	26
Rented accommodation	8	10
Camping	4	9
Holiday camps	5	6
Other	2	-

(1), (2) See separate references on page 199.

(c) The preponderance of the caravan is specially marked in Denbighshire and Flintshire. The following figures show the number of beds in various types of holiday accommodation available in five counties of North Wales which, together, account for 60% of all the holiday accommodation in the Principality.

<u>Accommodation</u> <sup>(2)</sup>	<u>Counties</u>				
	<u>Anglesey</u>	<u>Caernarvon</u>	<u>Denbigh</u>	<u>Flint</u>	<u>Merioneth</u>
Hotels	1,351	12,370	2,950	1,195	2,398
Guest houses	1,792	8,559	2,455	1,300	2,094
Bed and breakfast	1,905	17,315	4,365	4,010	5,105
Furnished rooms	1,550	10,240	2,805	4,670	4,610
Caravans	12,105	28,080	30,565	25,275	16,964
Holiday camps	-	12,000	-	2,500	-
Hostels, etc.	-	1,875	360	50	514
	18,703	90,439	43,500	39,000	31,685

More than two-thirds of all beds in Denbighshire and nearly two-thirds of those in Flintshire are in caravans, while in Caernarvonshire the proportion is less than one third.

#### The holidaymaker

(d) Compared with the average for Britain, Wales has a low proportion of elderly holidaymakers and a high proportion of people in the 30 - 50 age group with families. In 1961, 16% of all those taking their main summer holiday in Wales brought three or more children, compared with only 7% in the whole of Britain. Welsh holidaymakers also included a rather more than average proportion of people in the higher social classes, as defined by the Registrar General.

#### Transport

(e) Approximately 70% of holidaymakers visiting Wales travel by private car.

#### Coach trips

(f) There is little coach touring in Wales and only a modest number of day trips. Of an estimated 408,000 day trippers by coach in 1961, 247,000 came from the North-West. Of these, 127,000 went to the North Wales coast and 78,000 to Snowdonia.<sup>(1)</sup>

3. Origin of visitors to N. Wales

(a) The Council for Wales sample enquiry found the following distribution of visitors to Wales as a whole :-

<u>Origin</u> <sup>(1)</sup>	<u>%</u>
North West	24
North & North East	9
North Midlands	7
Midlands	22
Rest of England and Wales	38

(b) No separate information is available for N. Wales but it is known that about 77% of holidaymakers from Northern England went to N. Wales, against only 36% from the South. On a basis of 6 million holidays in the whole of Wales, therefore, the following approximate estimates can be made for N. Wales.

<u>Origin</u>	<u>Numbers</u>
North West England	1,200,000
North and North East	400,000
North Midlands	300,000
Midlands	1,000,000
Rest of England and Wales	800,000

4. The effect of a crossing

(a) The development of the industry could be affected by policy decisions about which there are two sharply contrasting schools of thought. One wishes to restrict the growth of caravan sites and camping facilities and to encourage that of hotels, on the ground that expenditure per head is much higher in the hotel and boarding-house section. Others - probably more realistic - recognize that the growth of the hotel side of the industry will be restricted (unless it were heavily subsidized) by the high cost both of building and services, and that the biggest increase in effective demand is likely to be for the fairly cheap, "do it yourself" family holidays. In the following paragraphs it is assumed that, while development in particular locations will be controlled, no attempt will be made either to restrict or to stimulate the over-all growth of any particular type of accommodation.

(b) Initially, the main benefit of a crossing would be felt by the 1,200,000 visitors to North Wales from the North-West. Their savings in time and travel costs are evaluated in the traffic study. Though important in total, the saving to an individual traveller is not large in relation to the cost of a main holiday of, say, one to three weeks duration. The number of people taking this kind of holiday in Wales therefore, is unlikely to be significantly affected by a crossing.

(c) The saving is much more important in relation to week ends and still more so in relation to day trips, either by coach or private car. For the person starting out from the North-West after work on Friday and returning on Sunday, large parts of the N. Wales coast and the mountain regions are now just outside comfortable driving range. A crossing would bring them within that range from a large part of South Lancashire. Thus there should be a considerable stimulus to week-end visits outside the normal holiday season. This would bring more trade to hotels and caravan owners and would stimulate the growing demand for "second homes" in North Wales.

(d) There would be a similar (and possibly even more marked) stimulus to day visits, both by private car and coach, which would both increase in number and extend further westward.

(e) While Snowdonia and North-West Wales would come within the range of a comfortable day trip, the North-East coast and the Welsh side of the estuary would be brought within an easy Saturday afternoon or evening run for many people in the Wirral and South Lancashire. This opens up the possibility of two further developments :-

- (i) the extension of the mass entertainment facilities already existing in the Rhyl-Prestatyn area, and
- (ii) the provision of new facilities for more individual types of recreation, e.g. sailing, canoeing, rowing, water ski-ing, riding and golf in North Wales and especially along the Welsh side of the estuary.

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#### References

- (1) Council for Wales and Monmouthshire: Report on the Welsh holiday industry. H.M.S.C., November 1963.
- (2) Figures supplied by Wales Tourist Board Ltd.

BENEFITS AND COSTS OF SCHEMES1. Introduction

(a) Both benefits and costs from Dee estuary schemes would arise in each year for a long time into the future. A reference year (1976) has been adopted to which all benefits and costs have been discounted at 8%. Present values in the economic sense have been calculated for 1 January 1976 on the assumption that annual cash flows occur on 31 December in each year.

(b) Major capital works, which would take more than a year to build have been treated as though their cost, plus the interest at 8% on a loan to finance their construction, were borne on 31 December of their year of completion. Thus the first stage of construction would be completed on 31 December 1975 and, although benefits would start to accrue on 1 January 1976, the total benefit for the first year has been taken to arise on 31 December 1976. Its present value therefore is 92.6% of the total amount and, for example, the corresponding figure for benefits in 1981 is 68.1%.

(c) The capital costs are based on current (1966) rates and prices with an allowance for contractors' mobilizations and miscellaneous items, with high allowances (up to 20%) for contingencies. The costs also include for engineering design and supervision.

(d) One per cent of the capital cost of the works has been taken as the annual cost of maintenance and administration, except for bridges where two per cent has been taken. Running costs (electrical energy and chemicals) have been included where appropriate.

(e) The present value of the benefits of roadworks has been taken to 2001 i.e. 25 years from 1976. The present value of the maintenance and administration costs has been taken over the same period but no allowance has been made for the depreciated value of the roadworks at the end of 2001.

(f) The present value of the benefits from waterworks has been taken in perpetuity but so has the present value of the maintenance, administration and running costs. In addition, the present value of the cost of replacement of the waterworks has been included: mechanical plant and equipment after 20 years; concrete structures and pipelines after 40 years and earthworks after 60 years.

(g) It should be noted that with a discount rate of 8% the present value of replacements is 10% of the capital cost after 30 years and 1% after 60 years. The resulting difference between the methods of analysis adopted for roadworks and waterworks is small and well within the accuracy of the estimate of the benefits.

## 2. Benefits

(a) The method of calculating the benefits to traffic from estuary crossings is described in appendix E3. The values calculated from the results of the assignments in the gravity model (appendix C4) are tabulated below :-

Crossing location and alignment letter	Present value in 1976 of the benefits to 2001. £m	
	with a third Mersey crossing	without a third Mersey crossing
outer zone	31	28
middle zone X	50	45
middle zone with 200,000 extra population	55	49
middle and inner zones XX	57	51
combined middle and inner zones Y	47	41
inner zone	13	12

As discussed in E3, 4(d), the benefits to traffic without a third Mersey crossing are used in the economic appraisal and appear in the table at the end of this appendix.

(b) The calculation of benefits of water supplies is described in appendix E5. Their present value is £39m for a development period of 60 years and £69m for a development period of 30 years.

(c) The benefit from land reclamation has been taken as the appropriate value of agricultural land following the discussion in appendix E6. The benefits for the particular schemes costed are given below :-

Scheme	Benefit £ m
outer line multi-purpose	2.7
separated-purpose middle/inner zone crossing	1.6
middle/inner zone multi-purpose	0.4
inner zone crossing	0.1

It should be noted that if the whole of the estuary to the line Point of Air - Hilbre were reclaimed the gross benefit would be £6.3m at the valuation adopted. The benefits calculated for land reclamation are less than one-tenth of those from either roads or water supplies; they have therefore not been listed separately since they are less than the order of accuracy of the estimates of the major benefits.

(d) No other benefits have been quantified although the provision of amenity and recreational benefits have been considered qualitatively in all schemes except those for the inner zone and bridge crossings.

### 3. Costs

(a) The costs of land acquisition (appendix E6 paragraph (j)) for all schemes are of the order of one per cent of scheme costs and are not listed separately in the table at the end of this appendix.

(b) When the traffic predictions have indicated need for an increased number of lanes within the first ten years of opening new roads, allowance has been made for building the formation to full width initially. Surfacing, however, has been staged to meet the predicted growth in traffic.

- (c) Specific alignments of the approach roads on either shore of the estuary are not shown on the drawings but characteristic routes have been examined and the costs reflect the more difficult terrain on the Welsh side.
- (d) Allowance has been made for the costs of any necessary interchanges within the crossing schemes and at the junctions with the existing road network. Where an interchange is already proposed, allowance has been made only for the new connection.
- (e) Apart from the number of lanes (taken as 12 ft wide throughout), adjustments have been made for highway classification to an all-purpose road or to motorway standard as required.
- (f) The cost of bridging the estuary has been estimated on the basis of comparable multi-span structures founded on deep alluvial deposits and exposed to marine conditions. Hard shoulders of reduced width (6 ft) have been included and the central reserve would be reduced to 8 ft. There would be a 12 ft cycle track and walkway on one side.
- (g) A large variety of embankment cross-sections would be required in a multi-purpose scheme, three examples being shown on drawing 17. A common feature, however, would be the low cost of hydraulic sand fill in relation to that of other materials. The significant element in the cost of embankments would be protection of the sand during and after construction (chapters 5.1 and 5.6). The unit cost of dredged sand would be about one-tenth of that for rip-rap protection and about one-fifth of that for boulder clay and mine waste for temporary containing banks. Allowance has been made for fascine protection of embankment toes against scour during construction, for blasting to compact the foundation sands and further compaction of hydraulic sand fill placed under water.
- (h) The minimum crest width of embankments would be 40 ft and the cost of a 24 ft road for maintenance purposes on all embankments has been included.
- (j) Half-tide training walls of rockfill would require extra fill due to the tendency to scour round the end of the wall during construction. This could be avoided by placing the rock on fascine protection. An allowance has been made to cover the cost of either method.

- (k) In all estimates of embankment quantities the estuary contours from the 1965 survey have been used, plus an allowance where appropriate for scour. Previous surveys show large differences in the bed configuration and there is evidence that the trend is continuing. Estimates of quantities in Phase II should be based on model predictions of the estuary contours at the time of construction, including the changes brought about by preceding works.
- (l) The size and form of sluices to discharge high river flows to the sea would be the subject of model testing. Meanwhile, estimates have been made based on experience in alluvial and estuarine conditions. For the expected discharges, the cost would be between £3m and £5m depending upon their position in the estuary.
- (m) In comparison with the sluices, the cost of fishpasses is small and is included in the same estimate.
- (n) The method of closure proposed is given in section 5.1.3 and shown on drawing 17. The estimated costs include a temporary trestle bridge 40 ft wide, protection of the channel bed with fascine work and a mound of tipped rock, the upper lifts of which would be selected large blocks to resist the crest velocities in the most severe stages of closure. Also included in the cost of closure would be a filter on the upstream side of the mound but not the hydraulic sand fill to complete the embankment section.
- (o) Grossly polluted trade effluents would be diverted past a tidal barrier (section 2.3.5). The cost of a sewer to carry the flows from existing outfalls, and the expected increase in those flows by the end of the century, rises rapidly if it has to be taken further than Flint. Its present value and that of extra pumps to discharge the increasing flows has been estimated at £1m for an outfall off Bagillt and at £4m for one two miles off Mostyn. If the sewer had to be taken out to sea beyond the Point of Air the cost would be about £10m. The present value of the pumping costs is taken with the other running costs in the table at the end of this appendix.
- (p) Pumps to lift water from the river into the bunded reservoirs would be of large capacity in relation to the reliable yield provided at any stage (appendix D1). Their cost and the cost of pipework to distribute the water amongst the reservoirs for reasons of water quality control (appendix D3) would be staged.

## TABLE OF BENEFITS AND COSTS

(£ million)

Scheme designation or location		When supply development period - years	PRESENT VALUE OF BENEFITS		CAPITAL FOR FIRST STAGE		PRESENT VALUE OF COSTS FOR WHOLE SCHEME																
			Crofting	Water	Totals	Water supply (see water supply and distribution)	Water treatment	Water transmission	Totals	Approach roads	Subsidiaries & roads	Closures	Islands and farm self supply	Amalgam provisions	Drainage	Sluices	Boojays	Tide efficient scheme	Minor adaptations and power for low tide	Salinity control scheme (see water supply and distribution)	Water treatment	Water transmission	Totals
FREDIE CHICKENGS ONLY	Order area	-	28	-	28	27	-	27	6	-	-	-	-	-	-	-	26	-	0	26	-	-	26
	Power cost	-	23	-	23	6	-	6	7	-	-	-	-	-	-	-	1	-	1	7	-	-	8
	Salinity W	-	63	-	63	32	-	32	6	-	-	-	-	-	-	-	26	-	0	26	-	-	40
SEPARATED PURPOSES	Order area covering	-	28	-	28	27	-	27	6	11	-	-	-	-	-	-	3	-	2	22	-	-	22
	Islands/town area	X	-	40	-	40	22	-	22	7	2	-	-	1	-	-	3	-	0	-	-	-	22
	coverings	XX	-	51	-	51	22	-	22	0	0	-	-	1	-	-	0	-	0	26	-	-	26
		Y	-	61	-	61	22	-	22	7	7	-	-	1	7	2	-	0	22	-	-	29	
	Water Supply		30	-	30	27	0	27	0	12	-	7	4	2	-	1	2	-	2	22	11	24	55
MULTI- PURPOSE	Water Supply		60	-	60	32	7	39	6	15	-	4	2	-	1	3	-	1	51	-	6	57	
	Islands/town area	X	30	40	70	32	0	32	7	7	-	4	2	-	1	3	4	0	46	11	24	71	
		XX	30	40	70	32	0	32	7	0	3	1	1	2	0	0	0	0	31	-	0	40	
		XX	30	51	81	32	0	32	6	16	0	22	4	2	-	1	3	4	40	11	24	75	
		Y	60	51	111	32	0	32	0	14	0	7	2	1	1	3	0	0	31	-	0	50	
		Y	30	61	91	32	0	32	7	0	4	2	-	1	4	-	0	4	31	11	24	66	
	water	Z	60	61	121	32	0	32	0	14	0	7	2	1	1	3	0	0	31	-	0	50	
		Y	30	67	97	32	0	32	7	12	0	2	-	1	0	-	4	4	40	11	24	71	
		Z	60	66	126	32	0	32	7	0	0	-	1	0	-	0	0	0	31	-	0	31	
		ZZ	30	71	101	32	0	32	0	12	0	2	-	1	0	1	4	4	40	11	24	77	
	order area	ZZ	60	51	111	32	0	32	0	14	0	7	2	-	1	3	1	0	31	-	0	50	
		S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ORDER AREA	Order area		30	51	81	32	0	32	0	16	0	2	1	2	1	3	0	0	70	11	24	105	
	Order area		60	31	91	32	0	32	0	12	0	1	1	2	1	3	0	0	60	-	11	82	

- NOTE: - 1. Small or infrequent benefits are not listed.  
 2. All figures have been rounded to the nearest million pounds.  
 3. Only the major categories of cost are shown, other categories have been combined under the major headings.  
 4. An identical quantity of work will have a lower present value if it is staged over a longer period.



- (q) Draw-off arrangements would also be staged. Allowance has been made for draw-off towers remote from the point of entry of the raw water, involving several miles of large-diameter pipe.
- (r) Appendix D3 shows that the water treatment will not be unusually difficult. The cost of conventional methods has been used with an allowance of 2 pence/1000 gallons for chemicals. The present value of treatment works and their running costs are given as a combined figure in the table.
- (s) Transmission costs are large in relation to the cost of water conservation. An analysis has shown that, where the quantity of water to be pumped increases steadily over the years up to 100 mgd on any one route, the lowest present value of the total cost of transmission is obtained by laying a large-diameter pipe initially. Further studies are required of the economies that could be made in the bulk transfer of water but, meanwhile, transmission costs have been estimated for pumping in stages of up to 75 mgd through 60-inch pipes and the total present value is listed in the table.

THE DEE ESTUARYSummary of scientific interest and of likely  
ecological effects of various possible estuary schemesMemorandum by the Nature Conservancy \*ORIGIN, GEOLOGY AND PHYSIOGRAPHY

1. Recent theories suggest that the Dee estuary, like that of the Mersey but so far as is known unlike any other estuary in Britain, was excavated by ice flowing in the opposite direction to the present drainage. This ice discharged through the gap between the Pennines and the Welsh Hills from a land-locked ice sheet which in glacial times occupied the basin of the Irish Sea. The estuary has unusually straight, parallel sides and an irregular solid rock bottom.

2. Superficial deposits overlie much of the basic rock structure adjacent to the estuary and extend beneath the estuarine alluvium. The depth of this alluvium is considerable and the process of siltation is still continuing quite rapidly. The alluvium is stabilized by marsh vegetation about the mouth of the estuary, along its flanks and extensively at the head. Elsewhere the unstabilized alluvium is being continually re-distributed, causing a changing pattern of creeks, mudflats and sand-banks. Blown sand forms dunes at Hoylake and Point of Air.

VEGETATION

3. Saltmarsh is the main vegetated habitat. It supports a range of plant communities which vary a good deal in relation to gradations in level above low tide mark and in salinity, but are not significantly different from saltmarsh vegetation types elsewhere in Britain.

4. Present records suggest that some thirty-six species of flowering plants and ferns found in the coastal and wetland habitats of the Dee estuary have a somewhat local distribution in the British Isles. All are known from at least twenty-five other localities, and fourteen of them from not less than a hundred sites in Great Britain. Eleven species are close to either their northern or southern limits of distribution, and five actually reach one or other of these limits in the Dee estuary. Of these, three occur on the saltmarsh and the others on the sand dunes or boulder clay cliffs adjoining the estuary.

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\* Component body of the Natural Environment Research Council

## INVERTEBRATES

5. The invertebrate fauna of the estuary varies considerably with habitat. Creeks and channels are rich in crustacea, including shrimps and crabs, while the pools support species of molluscs, crustacea, and nematode and annelid worms. Only a limited number of species burrow in the sediment forming the bed of the estuary, but those that do occur are very abundant. Their precise distribution is controlled by a variety of factors including salinity, exposure, substrate and water content within the sediments. On the surface of the open flats, where only truly aquatic species can survive, there are two widely distributed surface-living invertebrates - the shore crab, Carcinus moenas, and the snail Hydrobia ulvae. Populations of up to 12,500 Hydrobia per square metre have been estimated in some muddy inshore areas. There are also some burrowing molluscs which come to the surface temporarily, including the Baltic tellin, Macoma balthica, and the cockle, while mussels and winkles occur on stones on Heswall and Gayton sands. The saltmarsh areas provide shelter for many surface living invertebrates, especially arthropods. Thus the estuary has a diverse invertebrate fauna, but there is no evidence that any of the species found there is particularly rare or of outstanding scientific importance.

6. The invertebrate fauna provide a rich food supply for wildfowl. Goldeneye feed especially on the crustacea of the creeks, while ducks and waders frequent the pools. Burrowing invertebrates are taken especially by waders, whose bills are adapted for seizing animals below the surface of the substrate. Shore crabs on the flats are important as a food for goldeneye ducks, while the snail Hydrobia, possibly the most important species in the estuary for the wildfowl, is the staple diet of shelduck and taken in quantity by mallard, teal, pintail and redshank. The mussels and winkles of stony areas are taken by oystercatchers and purple sandpipers, while the arthropods of the salt marches form part of the diet of passerine birds, including skylarks and rock pipits.

## VERTEBRATES

### Fish

7. The Dee estuary supports a considerable number of inshore-feeding marine fishes and is traversed by migratory freshwater fish of which salmon are the most important.

### Birds

8. The Dee estuary has been recognised as among the most important areas in Europe for wildfowl, and is specifically mentioned in the 'Project

MAR' list published by the International Union for the Conservation of Nature and Natural Resources. Over twenty species, including eight of duck and twelve of waders, frequent it in appreciable numbers, especially during autumn and winter when it is a major feeding area for migratory species. As many as 500,000 wildfowl may inhabit the estuary at these seasons. The estuary also provides a wintering area for many thousands of passerine birds, notably skylarks and rock pipits. In summer, the resident and breeding populations are much smaller both in numbers of species and of individuals.

9. This ornithological importance, which is the outstanding scientific feature of the estuary, is due to :-

- (i) the large area of foreshore exposed for long periods between tides;
- (ii) the considerable range of habitats;
- (iii) the abundant supply of invertebrate food organisms;
- (iv) the availability of suitable resting places for birds at high tide;
- (v) the relative lack of disturbance;
- (vi) the low degree of pollution.

#### Mammals

10. The sandbanks west of the Hilbre Islands are among the few places on the north-west coast of England where grey seals haul out in numbers.

#### STATUTORY RECOGNITION OF SCIENTIFIC INTEREST

11. The scientific importance of the Dee estuary stems from :-

- (i) its physiographic features and peculiar origin;
- (ii) its large areas of marsh and flats, with their plant and invertebrate communities;
- (iii) its very large autumn and winter wildfowl populations;
- (iv) its potential for research and teaching. At present the estuary is used mainly by staff and students from the University of Liverpool who, over the past twenty years,

have made a detailed study of the progress of saltmarsh formation on the Cheshire side of the Dee and of the invasion of these marshes by the grass Spartina townsendii. Schools in Cheshire, Lancashire and Flintshire have also undertaken field studies in the estuary.

12. Because of this scientific interest the Nature Conservancy has notified to the local planning authority two areas within the estuary as Sites of Special Scientific Interest in accordance with the provisions of Section 23 of the National Parks and Access to the Countryside Act, 1949. One of these Sites includes almost the whole of the eastern side of the estuary, and the other the Point of Air. In addition, a statutory bird sanctuary has been notified (under the Protection of Birds Act, 1954), covering 5,750 acres at West Kirby cum Hoylake and Caldy, including the Hilbre Islands.

#### MODIFICATION BY HUMAN ACTIVITIES

13. The natural processes controlling the development of the estuary and its vegetation and fauna have been much modified by human activities. The most pronounced effects have been caused by numerous land reclamation schemes.

14. The introduction of the grass Spartina townsendii into the estuary in the 1920's as a means of stabilising mudflats has had far-reaching and, from the wildlife point of view, detrimental effects. This grass has now spread through much of the area; it threatens to destroy the normal saltmarsh succession while causing a speeding-up of the siltation process, thereby reducing vegetational diversity and greatly reducing the value of the flats and saltmarsh as feeding grounds for birds.

#### LIKELY ECOLOGICAL EFFECTS OF ESTUARY SCHEMES

15. Three possible crossing schemes are under consideration :-

- (i) bridge only;
- (ii) combination of bridge and embanked crossing (possibly with banded reservoirs and land reclamation);
- (iii) barrage only.

16. Whatever scheme were adopted its position along the estuary would be of vital importance. In general, the nearer the works are to the mouth the greater will be the consequent biological changes.

#### Bridge only

17. The piers of a bridge would interfere slightly with tidal flow and this would alter the distribution of alluvium locally. The biological significance of this would be negligible. If, however, the route of the bridge crossed Hilbre Island considerable disturbance to this important wildfowl roost would result.

#### Combined bridge and embanked crossing

18. This would exert a much greater effect on tidal flow and on the rate of silting. The consequences cannot be estimated without recourse to model tests such as those being carried out by the Hydraulics Research Station. There would almost certainly be considerable accretion of silt on both sides of the embanked sections which, downstream, would act as a focus for the further build-up of saltmarsh. In the early stages, this might compensate for the possible loss of saltmarsh due to reclamation and flooding with fresh water behind the embankment. However, these areas of accretion are likely to be colonised by *Spartina* and rapidly converted to high level saltmarsh of diminished value as wildfowl feeding areas.

19. Bunded reservoirs on the Cheshire side of the estuary would inundate large areas of saltmarsh. Because these areas are already being invaded by *Spartina* their loss would not be particularly serious unless the main site of research work carried out by Liverpool University were involved. But the inundation or drainage of areas not yet colonised by *Spartina* would result in reduction of the valuable feeding area for waders. Certain high tide roosts for waders would probably also be lost, but the new areas of permanent water would be attractive to ducks and geese.

#### Barrage only

20. This would completely change the scientific character of the estuary. Water above the barrage would be fresh and that below saline. A profound effect would be exerted on tidal flow, resulting in considerable accretion on the seaward side of the barrage.

21. If the Hilbre-Point of Air line were chosen for the crossing the whole estuary would be converted either to agricultural land or to a freshwater area, or to a combination of both. The scientific interest referred to in para 11. would be completely changed. While the changes themselves would provide a suitable field for research and education and any large new body of fresh water would be of continuing biological interest, these gains are unlikely to compensate for the virtually complete loss of the estuarine ecosystem and the destruction of the wader habitat. Alternative feeding areas of any size to which the displaced birds might resort (such as Morecambe Bay) are rare and, in many cases, are already under consideration for barrage development.

### GENERAL CONCLUSIONS

22. Either of the schemes involving an embankment will have some effect on the scientific interest, and the nearer the works are to the mouth the more extensive this effect will be. It is important that when a more definitive crossing scheme is being prepared, further and more detailed studies of its ecological implications are undertaken. No doubt there will be full consultation at this stage between all those likely to be affected by the project. The Nature Conservancy would be pleased to advise as appropriate on steps to ensure that scientific and wildlife interests are conserved and, where possible, enhanced (for example by setting aside areas reserved for wildlife and for educational purposes).

23. Under certain circumstances the creation of new freshwater areas would provide excellent opportunities for diversifying the existing habitat in the Dee estuary. This diversification would be of maximum benefit if substantial areas of saltmarsh and flats were retained unchanged on the seaward side of the crossing and if the Hilbre Islands were left undisturbed. If the new freshwater areas were carefully planned and managed on ecological lines, with multiple use in mind, and if full use were made of the research opportunities to study the resulting major biological changes, losses to the existing scientific interest would to some extent be offset.

24. If the new areas were to be exploited solely for commercial and recreational purposes, the Council, in accordance with the provisions of Section 23 of the Countryside Act of 1949, would be bound to notify the responsible authorities that a serious loss of scientific interest would result.

RESEARCH ON DEE SALMON & SEA TROUT

(required only if multi-purpose rather than pure  
bridge crossing scheme chosen)

(a) In Phase II\* of the study, the following research subjects are proposed :-

- (i) movements of salmon & sea trout in coastal waters approaching the Dee; their behaviour patterns when seeking to run up river, including timing. These, of course, are broad questions, costly to try answering fully and research would be confined to aiding solution to specific items below;
- (ii) use of fresh water discharges to best advantage;
- (iii) conditions most inductive to getting fish to run (amount of water, quality, temperatures<sup>+</sup>, pressure, etc.); upstream and downstream approach shapes to fish passes;
- (iv) methods of acclimatizing smolts to salt water;
- (v) causes of losses of Dee fish: e.g. overcrowded spawning grounds; predation on young by trout and in coarse fishing reach between Chester and south of Holt; pollution (but assumed negligible after sewage effluent improvements and installation of trade waste disposal sewer);
- (vi) means of improving fishing by reduction of predation in river e.g. use of traps and transporting young descending fish past coarse reaches; any other feasible loss reductions.

(b) Several of the above subjects would involve large-scale tagging of fish and this could be done in conjunction with the Dee and Clwyd River Authority's present tagging programme (in 1966, some thousands of hatchery smolts were tagged).

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\* or initiated even before then and, in any event, closely linked with and not duplicating similar work on migratory fish problems by the Water Resources Board's Fisheries Committee and other bodies.

+ including experiments to induce early running by raising the temperature of discharge artificially e.g. with a proportion of non-toxic industrial cooling water.

(c) The existing fishery research school in the Zoology Department of Liverpool University might carry out this research or a special series of 3-year research fellowships might be instituted but it is suggested that the precise methods of directing and financing the work are matters for consideration by the Technical Working Party and Steering Committee. An appropriate financing body might be the Natural Environment Research Council. Another suggestion would be to finance partly from income expectation from any new fisheries created.

## DATA ON DEE SALMON FISHERIES

Year	Commercial netting (returns by netsmen)		Rod and line (bailiffs' reports)		Totals	
	nos.	lbs.	nos.	lbs.	nos.	lbs.
1961	2,759	26,895	1,156	15,245	3,915	42,140
1962	3,321	26,719	1,036	12,156	4,357	38,877
1963	3,224	28,921	1,315	15,369	4,539	44,290
1964	4,255	35,026	1,067	12,752	5,312	47,778
1965	3,346	28,919	1,530	17,380	4,876	46,299
approx. averages	3,400		1,200		4,600	44,000

In 1965, license receipts by the River Authority (only for salmon and in the river Dee) were :-

netsmen (36 license holders and 101 endorsees)	£500 (approx.)
rod and line	£3,800 (approx.)

The effective length of salmon fisheries in the river Dee and tributaries is estimated to be about 75 miles (x 2 banks).

DATA ON SEA FISHERIES(see also section 2.6.2 and drawing 13)

(a) The sea fisheries which concern the Lancashire and Western Sea Fisheries Committee exclude salmon and are seaward of a line from around Caldy - Greenfield. The catches comprise shrimps, cockles and some wet fish. Shrimps and cockles are much the most valuable part of the catch. The finest cockles in Britain are found off Hoylake. Statistics of catches and values in recent years are attached, as collected by the Committee for the Ministry of Agriculture, Fisheries and Food (who publish only totals). The year-by-year fluctuations are those normal to this type of activity but are affected by the destruction of the cockle beds by frost in 1963. This will reduce yields until the beds have had time to re-set.

(b) The fishery has 18 full-time vessels and about 31 men. 12 of the vessels and 22 of the men work off the Cheshire side, mostly off Caldy. There is also part-time effort using perhaps 40 boats off Connah's Quay. The official catch is shrimp and flounder. The part-time effort would add perhaps one-twelfth to the statistics given. The vessels are worth an average of around £800 and are fairly specific. But there would probably be a reasonable local market for them were the fishery destroyed. Given reasonable alternative employment opportunities, the economic loss to the community from destruction of the fishery would be only the "value added" by the fishery itself, not the total value of the catch. It should also be noted that the labour force, though small, is concentrated in a few "traditional" families.

YIELD OF DEE ESTUARY FISHERIES BY TYPE,  
WEIGHT AND WHOLESALE VALUE

(1960 - 65)

	<u>HOYLAKE TO CONNAH'S QUAY</u>		<u>CONNAH'S QUAY TO RHYL</u>	
<u>1960</u>	<u>Weight (cwt)</u>	<u>Value (£)</u>	<u>Weight (cwt)</u>	<u>Value (£)</u>
Wet fish	194	1,135	118	347
Cockles	4,527	2,324	18	9
Shrimps (boiled)	409	2,172	370	1,890
Prawns	23	412	-	-
Total Value		<u>£6,043</u>		<u>£2,246</u>
<u>1961</u>				
Wet fish	111	587	230	786
Cockles	16,340	8,170	4	2
Shrimps (boiled)	759	5,144	182	1,243
Prawns	7	164	-	-
Total Value		<u>£14,065</u>		<u>£2,031</u>
<u>1962</u>				
Wet fish	17	49	156	484
Cockles	17,293	8,748	-	-
Shrimps (boiled)	1,018	6,478	241	1,626
Prawns	3	76	-	-
Mussels	70	51	-	-
Total Value		<u>£15,402</u>		<u>£2,110</u>
<u>1963</u>				
Wet fish	28	161	106	482
Cockles	4,493	4,451	6	135
Shrimps (boiled)	1,219	7,712	290	2,689
Total Value		<u>£12,324</u>		<u>£3,306</u>
<u>1964</u>				
Wet fish	40	205	320	1,945
Cockles	26	32	2,916	2,928
Shrimps (boiled)	963	7,623	262	2,040
Total Value		<u>£7,860</u>		<u>£6,913</u>
<u>1965</u>				
Wet fish	87	301	232	930
Cockles	-	-	20	30
Shrimps (boiled)	627	5,266	408	3,165
Total Value		<u>£5,567</u>		<u>£4,125</u>



# Dee Crossing Study Phase 1

Ministry of Housing  
and Local Government

A report to the technical  
working party

Binnie and Partners  
in association with  
G. Maunsell and Partners  
and Economists Advisory Group

London  
Her Majesty's Stationery Office  
1967





# DEE CROSSING STUDY

## PHASE I REPORT

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